AD-A122 281

AD

AD-E400 931

TECHNICAL REPORT ARLCD-TR-82014

SIMULATION OF AMMUNITION PRODUCTION LINES

WILLIAM MENKE
DAVID TRAN

NOVEMBER 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report ARLCD-TR-82014	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): SIMULATION OF AMMUNITION PRODUCTION LINES	5. TYPE OF REPORT & PERIOD COVERED: Final, Nov 78 to June 82
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): William Menke and David Tran	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: ARRADCOM, LCL, Munitions Systems Div (DRDAR-LCU-M), Dover, NJ 07801	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: MMT 5796682
11. CONTROLLING OFFICE NAME AND ADDRESS: ARRADCOM, TSD, STINFO Div (DRDAR-TSS), Dover, NJ 07801	12. REPORT DATE: November 1982
	13. NUMBER OF PAGES: 67
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Availability
Bank
Basic time interval (BTI)
Binomial distribution
Buffer sizes
MMT-Simulation program
Metal parts
Mean time between failure (MTBF)
Mean time to repair (MTTR)
Production rate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Automated metal parts production facilities are complex because they are integrated with automated material handling systems, centralized chip transport systems, and automatic gaging; therefore, it is more difficult to predict monthly production throughput. The primary objective of this program is to develop a methodology to simulate production line behavior through computer modeling. The need to develop more reliable input data (such as MTBF and MTTR) is recognized and methodology to calculate buffer size through use of the binomial distribution is proposed.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ACKNOWLEDGMENT

The authors wish to acknowledge the efforts of National Presto Industries, Mason Chamberlain Incorporated, and Norris Industries for the data provided in support of the project.

Special acknowledgement is made to Edward Loniewski, Quality Assurance Division, ARRADCOM, for his special efforts in developing the General Modeling (GENMOD) program.

8-880- 4287
8-880-3596 (O'Neill)

CONTENTS

TABLES

FIGURES

INTRODUCTION

This project was initiated to develop a methodology to predict production capability of a given metal parts line through computer simulation. At the present, the quantity of production equipment required to meet a specific production rate is computed on the basis of past experience. However, it is apparent that production models for such facilities should incorporate today's technology in the field of computer simulation. As production equipment becomes more complex and subsystems are added to the facility to enhance automation, the need for computer simulation becomes more apparent since it is becoming more difficult to predict production capability as these subsystems are added. In the past, a production facility consisted mainly of semi-automatic lathes with a manual roller conveyor, some powered conveyors, manual gaging, and manual chip removal. A modern facility integrates automated machine tools, material handling, chip transport, and gaging.

The machine tool is serviced by a centralized completely automatic handling system, a centralized automatic chip transport system, and automatic gaging. The subsystems, material handling, chip transport, and automatic gaging, can directly and adversely affect production throughput and the monthly production capability of the facility. Past methods of predicting production capability counted the number of machine tools per operation and related production rates to forecast production capacity as a whole. This can no longer be done in a modernized facility. With the introduction of automated systems into a facility, personnel are no longer relied upon to maintain throughput by manually moving shell, shoveling chips, or manually gaging parts. Emphasis is now placed on these automated systems and must be considered in predicting throughput and monthly production capabilities of modern facilities.

This report covers the simulation of various metal parts lines using existing simulation models as well as the development of alternate models with which various line characteristics and configurations are developed and tested. The problems of acquiring the data required for simulation that was not readily available from the industry is addressed as well as developing a methodology to solve buffer sizes for automated material handling systems necessary if any accuracy is to be obtained from the prediction model.

Theoretical results obtained from these various simulation models are compared to actual production rates and design rates to which several conclusions and recommendations will be discussed.

INVESTIGATION OF VARIOUS SIMULATION METHODS

Simulation has been defined as the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (ref. 1).

The initial effort in this program was to determine what simulation models were already available. It was found that a profusion exists in simulation programs for production lines. The problem was in finding and selecting the proper program for our particular application. Two programs appeared to be most suited for our needs, one was in simulation language titled General Purpose Simulation System (GPSS) and the other General Modeling (GENMOD) developed and in use at ARRADCOM. Both GENMOD and GPSS are simulation models that use software packages which process the user's particular lines and provide various output information. They are general purpose simulation models and languages which, when compared to ordinary general purpose programming languages, differ in that the simulation language incorporates means for controlling the sequence in which events occur. Another advantage of the two models is that the simulation languages provide builtin diagnostic programs which check for logical error, syntax, and capacity violations.

Simulation models may be either continuous change or discrete-event types. Continuous change models are appropriate in simulating a system which consists of a continuous flow of information or material counted in the aggregate rather than in individual terms. In discrete-event models changes in the system are conceptualized as distinct occurrences; parts flow through the system requiring the performance of an operation on the part before it can move on to the next operation. Queuing theory becomes important in that parts may wait in line before being serviced. Information regarding the behavior of the model is tabulated and the results indicate what happens under a particular set of assumptions. Both GPSS and GENMOD are discrete-event type simulation models and are considered more appropriate than continuous change models when simulating metal parts ammunition lines.

Based on the investigation of the various simulation programs found available at the time, the GENMOD computer program was selected as the most appropriate program for our intended use. It is a generalized model which can investigate various automated production lines and the efforts of proposed design changes without constructing an entirely new model, thereby saving costly time in making models unique to our production line alone (ref 2).

DATA ACQUISITION

For any simulation program to be accurate, the data input must also be accurate and this presented one of the major problems at the very beginning of this project. The precise data required for most of the simulation programs was not available. Most simulation programs under consideration for our application required mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR) data for the production equipment to be simulated. A review of data in the industry particularly in projectile metal parts plants revealed such data, at least in the desired form, was not available. Most plant operators knew the availability of their equipment but not the MTBF or MTTR. Availability is defined here as the percentage of time that a unit of production equipment will operate when requested. Technically it is defined as the MTBF divided by the total time available or MTBF plus MTTR.

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF + MTTR}}$$

Although fairly reliable data on availability of equipment based on past experience could be readily obtained, the MTBF and MTTR needed to run any simulation program could not be accumulated. It was apparent that MTBF and MTTR data had to be collected.

All published reports were screened to determine the available data. Mason Chamberlain Incorporated, the operator of a new facility now under construction, had contracted with GARD Incorporated for a report (Sept 78) to the Project Manager Base Modernization office to analyze the Mississippi Army Ammunition Plant (MSAAP) complex using the GENMOD program. GARD encountered the same problem of attaining MTBF and MTTR data. GARD reviewed downtime records from the various Chamberlain plants at Scranton, Pennsylvania, New Bedford, Massachusetts, and Waterloo, Iowa and developed MTBF and MTTR values (table 1) for the MSAAP facility for the M483 projectile metal parts. GARD then ran the GENMOD program and the results were encouraging in the respect that the design rate for the line was predicted using reasonable buffers on the automatic material handling system of 320 spaces in all but the forge, heat treat, and phosphate and lube banks.

A review of the data together with the associated availability leads to some questions as to the reliability of the data. All of the availability numbers appear to be too high based on past experience. For instance, all availabilities except for forge equipment are around 95%, whereas the expected availabilities are in the order of 80% or possibly lower in some cases.

Because of this doubt, it became apparent that more information with greater accuracy was required for an accurate simulation to be achieved. Fortunately, the National Presto Industries (NPI) in Eau Claire, Wisconsin that produced the 105-mm M1 HE projectile in a large volume was known to keep good maintenance records. The company was visited with the intent of obtaining equipment operating records for statistical analysis yielding MTBF and MTTR values. Under government auspices, NPI conducted a rebuild and modernization program on their number one forge line which culminated in an equipment proveout in the spring of 1973. During this proveout, extensive downtime records were taken extending over a period of 2 months during which the line ran 24 hours a day, 5 days a week. An example of the record sheet is shown in table 2. Information of this caliber proves invaluable as far as input data necessary to running a computer simulation.

The forge line consisted of six operations in series with each beginning with induction heating the billet to approximately 1060°C (2100°F). The billet then goes through a high pressure water descaler to remove iron oxide buildup on the surface caused by heating. The block, cabbage, and pierce forging operations on one transfer press are than performed on the billet producing a bottle type configuration. The forged shell is then control cooled to room temperature to produce uniform metallurgical properties throughout the shell.

A failure event in this line was considered to be any repair needed in any one of the six operations. This failure results in a loss of production. Various uptimes (MTBF) and downtimes (MTTR) were calculated from the first two columns of table 2. This forge ran 24 hours without any stops for lunch or breaks;

therefore, any stop in the line was due to failure in machine operation. To illustrate a calculation, the table shows that at 4:00 the forge went down and started up at 4:01 producing a downtime event of 1 minute, then ran from 4:01 to 4:35 producing an uptime event of 34 minutes. The same analysis was used throughout the study covering two months in which approximately 1600 individual uptime and downtime events were recorded.

The time-to-failure and time-to-repair events were totaled and categorized into time intervals for graphical purposes. By individually graphing the frequency of repairs versus the time-to-repair, histograms were produced which can visually be interpreted to follow negative exponented functions.

The first histogram (fig. 1) is a graph of frequency of failures versus time between failures which shows that approximately 180 times the forge line was running between 0 and 15 minutes before a repair was needed. The next interval shows that approximately 150 times the forge was running between 16 and 30 minutes before a repair was needed, etc. The overall pattern appears to be a negative exponential function. The MTBF was calculated to be 59.08 minutes and is defined as average MTBF $= \bar{X} = \frac{X}{N}$, where X = individual MTBFs and N = number of occurrences.

The second histogram (fig. 2) is a graph of frequency of repairs versus time to repair which shows that around 350 repairs were needed taking between 0 and 5 minutes. The second interval decreases sharply in number of repairs, 150 repairs taking between 6 and 10 minutes. Again the pattern appears to be a negative exponential function. The MTTR was calculated to be 13.64 minutes.

These figures do not include catastrophic failures which alter the two figures to 53.02 min and 27.27 min for MTBF and MTTR, respectively. The forge line runs at an availability of 82% until a catastrophic failure occurs which then drops the availability to approximately 65% overall. A catastrophic failure is defined as a failure which causes a loss of production whose magnitude extends significantly beyond the range of normal expected values. Experience has taught production and manufacturing engineers in these plants to bank one week of production forgings in order to supply machines down the line with parts to compensate for the catastrophic failures while repairs are being made on the faulty piece of equipment.

The theory that both histograms are exponential in nature was tested statistically by using the Kolmogorov-Smirnov Goodness of Fit Test (table 3). This test is based on a comparison of the cumulative frequency distribution specified by the theory to the observed cumulative frequency distribution. Therefore, this test compares, interval by interval, the areas of a theoretical histogram generated by the specified function to the observed histogram. The test states that when subtracting the calculated from the observed a good correlation exists if the difference is close to zero.

$$Dx = \max\ [F(x)\ \text{calc} - F(x)\ \text{obs}] \quad \text{(ref 3).}$$

All values approach zero indicating that distribution is close to the assumed exponential (table 3).

Test results show that the failure cycle and the characteristics of the forge line can be identified by the negative exponential function of the form

$$Y = Ae^{-At} \text{ where } A = \frac{1}{\text{mean}} \text{ and } e = \text{epsilon}$$

Time-to-failure equation

$$Y = \frac{1}{59.08} e^{-t/59.08}$$

Time-to-repair equation

$$Y = \frac{1}{13.64} e^{-t/13.64}$$

These equations are important for computer simulation, since events occurring in time have now been shown to have a pattern of occurrence which can be imitated, thereby increasing knowledge of line operation and design. However, in order to simulate a line, added information is needed on equipment other than just the forge line; i.e., machine tool turning equipment.

The opportunity to collect data on machine tools came during the proveout of the 155-mm M483 metal-parts line at Norris Industries and was collected for a period of 20 days, 8 hours a day.

Data sheets used during the proveout (table 4) are similar to those used during the forge line proveout, except for the column marked event code. This column is used by the data collector to identify what type of event caused loss of production to the machine and is broken down into eight categories as can be seen on the bottom portion of the sheet.

A computer program, developed by ARRADCOM's Quality Assurance Division, analyzed the proveout data and provided information detailing machine breakdowns, tool changes, and observed production rates. An example of a computer printout of the daily downtime record sheets is shown as tables 5 and 6 with table 7 providing a summary for a particular machine for the overall test. A system summary is also provided (table 8) analyzing by machine and by operation various machine operating characteristics.

With the acquisition of this data (MTBF and MTTR values) is was possible to simulate metal parts ammunition lines by computer.

SIMULATION OF VARIOUS AMMUNITION LINES

Norris Industries

The first line to be simulated was the Norris Rough and Finish Turn M483 line whose input data is listed in table 8.

The first simulation run was made with the control points (buffers) between operations made unlimited (i.e., the buffers can never fill up, the maximum capacity is infinite). Helpful information concerning an imbalance in line design can be extracted from the average, maximum, and final buffer content summary (table 9). In this case buffers 8 and 12 both averaged a higher rate of contents due to either an over or under production of an operation on either side of each buffer. The category control point data (table 10) identifies this problem more specifically by the maximum input and maximum output for each buffer. Buffer 8 received 22.8 parts every basic time interval (BTI) while it released only 12.8 parts per BTI. The basic time interval is defined as the real time equivalent to a single step through a GENMOD model, in this case 1 BTI equals 15 minutes. The same is true for buffer 12 which accepts 25.1 parts per BTI (100.4 parts/hr) and releases 11.7 parts/BTI (46.8 parts/hr). The decision as to which side of the line is at fault relates to the intended design rate of the line, which in this case is 15,000 acceptable units per 500-hour month. An average rate of 30 net parts per hour was intended thereby identifying the problem as being an overfed buffer in each case. Elimination of one machine in both operations 210 (Rough Turn ID-OD) and 250 (Finish Bore Nose) will not affect the intended designed production rate since the remaining machine can carry the necessary production load. Norris Industries actually removed one machine from operation 250 and relocated operation 210 to provide extra buffering capacity.

Probably the most helpful output information is that identified as projected average outputs. The following figures identify the capability of the subject line in daily, weekly, and monthly figures.

Projected average outputs

per basic interval	9.86 (0.66 per min)
per 27 interval shift	270.0
per 3/8/5 week	4043.0
per 63 shift month	16979.0

The first run using unlimited buffers plus input data compiled from the lines own proveout indicates a production capability of 16,979 parts/500-hour month. The second run analyzing the Norris line is basically identical to the first except that limits were placed upon each individual buffer, these numbers being estimates of actual buffer capacities during proveout. In this case the overall production rate is lowered to 16,036.

A comparison between the two simulations of key buffers in the line whose contents varied during the simulation is shown in table 11.

Placing limits on buffers 8 and 12 of 15 and 43 parts (where in an unrestricted situation these are constantly filling up) shows that normally low content filled upstream buffers are now filling due to "pinchpoints" in the line downstream. These buffers are identified as numbers 4, 5, and 6 which are between the weld, heat treat, and turn O.D. operations. By increasing the capacity of buffers 8 and 12, the line will be able to handle lower capacity buffers in the weld, heat treat, and turn O.D. areas.

Another way of analyzing the projected rates is to compare it with actual production rates for accuracy within the simulation run. This can be done by comparing production rate of operation 305, the last operation in the simulation, to the proveout. By using the proveouts daily summary sheets (tables 5 and 6) and relating total parts processed to scheduled uptime, an overall rate of 37.95 parts per hour results. GENMOD identified machines 36 and 37 in the simulation to be those of operation 305, and by calculating the total parts processed by each machine to the scheduled production run, a rate of 37.88 parts per hour results. Both rates correlate well which lends to a high degree of confidence in the output information generated by GENMOD on the Norris 155-mm M483 line.

Mississippi Army Ammunition Plant (MSAAP)--Mason Chamberlain Inc.

The next facility to be simulated was the MSAAP 155-mm M483 line (fig. 3) currently under construction and operated by Mason Chamberlain, Inc. Production rates were obtained from equipment proposals while MTTR and MTBF values were extracted from similar equipment at both Norris and National Presto (table 12).

The first simulation of the line allowed all buffers between each operation to be infinite. Downtimes for large equipment such as stress relieve and cool, phosphate and lube, and clean were set at 1 hour with uptimes ranging from 160 to 125 hours. By doing this the line would be run at peak production output without having any critical large equipment being down. This places a greater strain on other buffers and by placing no limit upon each, imbalances in the line will show up in the buffer content summary as large numbers. A list of the buffers and operations which surround each are shown in table 13.

Buffers 4, 8, and 15 are located around large equipment such as phosphate and clean. Here each buffer built up its contents even though the large machinery experienced high availabilities with low downtimes. This illustrates the need for banking at such areas in metal parts lines which is exactly what facility design engineers do based upon experience.

Buffer 2 which is between operations shot blast and concentric turn has parts building up in it throughout the simulation. Part of the reason for this is the high production rate of shot blast (396/hr) versus concentric turns (331/hr). The other reason is concentric turn's MTBF is half that of the shot blast value and therefore experiences a buildup of parts in buffer 2.

Between operations bore nose and rough turn body is buffer 7 which averaged 1,628 parts. MTBF and MTTR values for each operation were made the same so the imbalance must be due to production rate differences of 360 per hour versus 324 per hour.

Buffer 21 also has a high average of 211 parts. Both operations (Fiberglass Wrap and Turn Fiberglass) have the same production rates and in examining the MTBF values it is shown that the wrap machines only stay running half that of the turn equipment. Why does buffer 21 fill up? The answer can be found by examining table 14 where total failures for each operation are listed. Operation 1155 (Turn Fiberglass) experienced a total of 579 failures for an availability of

83.93%. Operation 1160 experienced 464 failures for an availability of 88.82%. Since operation 1165 had more failures, buffer 21 had to build up its contents. The quoted production rate for the simulation was 138,908.

All buffers in each simulation having inspection equipment were limited to 130 which is a half-hour production. The two runs with inspection operations included differ only in the MTTR values for the large equipment previously identified as heat treat, phosphate and lube, stress relieve and cool, and clean. The first assumes a MTTR of 1 hour, the second 8 hours. The results of such an assumption reflects upon the projected outputs with the 1-hour downtime run yielding 126,984 parts per 500-hour month, while the 8-hour downtime run projects only 103,884 parts per 500-hour month. The design rate of the line is 120,000 per 500-hour month.

A summary of various simulations made on the MSAAP line using different buffer sizes and downtime values with the resulting production rates is shown in table 15. A graph of the runs (fig. 4) shows production rates as a function of buffer size between operations. The importance in keeping downtimes of large equipment at a minimum is shown in runs 1 and 3 (table 15) which keep the total buffering capacity constant (130) per operation and varies downtimes from 1 hour to 8 hours the projected production rate drop from 127 K to 105 K.

The definite correlation between production rate and buffer size is shown in figure 4. The larger the buffer the greater the lines ability to achieve the design rate. Downtimes of 8 hours on large equipment necessitate buffers in the area of 500 in order to meet rate. Downtimes of 1 hour on large equipment allow buffers to be as low as 130 and still meet rate.

The simulations show there is a tradeoff between repair rates on equipment and buffer sizes necessary in absorbing unscheduled downtimes to meeting designed production levels. This emphasizes the need for banking around heavy equipment and supports good maintenance policy to keep in-house inventory at low levels.

Louisiana Army Ammunition Plant--Thiokol Corp.

The Louisiana Army Ammunition Plant's (LAAP) 155-mm M483 metal parts line (fig. 5) was simulated using data (table 16) from the Norris Industries proveout. Various runs were made using different MTBF and MTTR values and buffer sizes. As should be the case with initial computer simulations using GENMOD, unlimited buffers were used to first identify any imbalances or critical areas in the line. In the average buffer content summary (table 17), buffers 1, 3, 7, and 9 all have high values except the last one. Buffers 1 and 7 are both high and should be because they precede operations nick and break and remove ring which run at high production rates; remove ring also has a high availability as well. Buffers 3 and 9 identify the forge and heat treat areas which, from experience, identifies necessary bank locations. All other buffers show low average contents indicating a well designed balanced line. The production rate in this run was predicted to be 57,253 per month.

Runs were made varying the MTBF and MTTR values (table 18) on operation 1110 (slow cool) and on operation 1270 (heat treat). As predicted, the runs with long repair rates yielded lower monthly production rates when compared with runs which used short repair rates. This is true even when the availabilities are made higher for long repair rates when compared with short repair rates and lower availabilities on operations such as heat treat and slow cool. An explanation is that key operations (1 machine) such as slow cool or heat treat have a great affect on production when experiencing long repairs causing depleted downstream inventories and requiring extra time in replenishing buffers to stable capacities.

Buffer limits also place restraints on predicted production rates to an even greater degree than that of MTBF and MTTR values (table 19). By placing limits of 500 (at forge and heat treat areas) and 88 (actual buffer sizes) on the line, the production rates falls from 59,717 to 51,384. However, run BAESF80 used the large downtime figures of 158 minutes. By changing this number to 56 minutes (run BAESF32) the production rate can be raised to 58,581 per month with the same buffer limit of 500 and 88.

These computer simulations show the various ~~fluctuations~~ changes in production levels that occur based upon ranging uptimes and downtimes as well as buffer sizes. The computer simulations of the LAAP line show that downtimes of the magnitude of 189 minutes (on key operations) will prevent achieving the designed production rate of 63 K per month, but if reduced to approximately 60 minutes, production approaches the design rate. This is true even if the uptimes are as large at 790 minutes and a low as 158 minutes. By decreasing the downtime of such operations, buffer sizes of 500 and 88 will work effectively.

MATERIAL HANDLING BUFFER SIZE

Along with MTBF and MTTR, buffer size must also be provided as input to any simulation program. The program selected for our studies, GENMOD, is no different and a methodology to derive the proper buffer size became highly desirable. Initial efforts in establishing realistic buffer sizes consisted of contacting material handling system contractors. These efforts revealed that no system exists and that buffer sizes are established rather arbitrarily by the buyer of the material handling system (MHS) and in some cases by the seller of the MHS. Since there has been very little experience in the projectile metal parts business with automated MHS, review of past histories in existing facilities was not very helpful. Therefore, initially the simulation programs were run based on either infinite buffer sizes or some arbitrary buffer size based on cost consideration and very limited experience.

If any simulation program was to be reliable, a methodolgy would have to be developed to derive buffer sizes based on some mathematical principles. The methodology developed and used for this program is presented here.

It should be understood what the function of a buffer is and how it relates to the MHS and the plant operations. It should be noted that when we have several machines in each operation these machines are turning off and on randomly, based on their availability. The real time production rate at each operation in a sequence of operations varies accordingly. In such a situation the MHS must have buffer to meet one of two conditions. Consider the case where you have a MHS between operation A and operation B.

Operation A — Buffer — Operation B

If operation A for a short period of time is producing more parts than B, the buffer (MHS) must absorb parts from operation A until operation B can accept these parts. On the other hand if operation A for a short period of time is producing less parts than B, the buffer (MHS) must provide parts to operation B until operation A comes back up to speed. These variations (speed or rate) of output of A and B are caused by the random turning on and off of several machines in each operation in accordance with their respective availability. It was stated earlier that availability which is more readily known for production equipment consist of

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

Unlike the situation for GENMOD where we must know the actual values for MTBF and MTTR for each type of equipment, the availability (A) is sufficient information for calculating buffer size for the methodology presented here. If it is stated that a machine tool has an availability of 80%, it is expected to operate 80% of the time. This is a life or death, yes or no situation. A machine is either running or it is not and no other condition exists. Further, these two events are exclusive of each other and together these two events, on or off, make up the complete time; no other event exists. Such a situation lends itself to the binomial distribution (fig. 6) which was used to develop buffer sizes for a specific application or production line. The following explanation is an example of the precedure followed.

Consider the case where you have a line consisting of a series of operations where you want a production capability of 65,000 units per 500 working-hour month. Therefore, the desired throughput at any time would be 65,000 divided by 500 or 130 units per hour.

$$\frac{65{,}000 \text{ units/month}}{500 \text{ hour/month}} = 130 \text{ units/hour}$$

The 130 units per hour is the mean throughput value.

Now consider the situation where there are two operations, A and B. In operation A assume five machine tools are required to meet the production rate and six machine tools are required in operation B. In addition, assume that the availability of these machine tools is 80% or 0.8. Therefore, in operation A (5 machines) 26 parts per hour net or 32.5 parts per hour ~~gross~~ max must be produced for each machine.

$$\frac{130 \text{ parts/hour}}{5 \text{ machines}} = 26 \text{ parts/hour/machine (net)}$$

or

$$\frac{26}{0.8} = 32.5 \text{ parts/hour/machine } (\cancel{\text{gross}} \text{ max})$$

The actual cycle time for the machine in operation A is 110.77 seconds/part.

$$\frac{3600 \text{ seconds/hour}}{32.5 \text{ parts/hour}} = 110.77 \text{ seconds/part}$$

In operation B (6 machines) 21.667 parts per hour net or 27.0833 parts per hour ~~gross~~ max must be produced for each machine.

$$\frac{130 \text{ parts/hour}}{6 \text{ machines}} = 21.667 \text{ parts/hour/machine (net)}$$

$$\frac{21.667}{0.8} = 27.0833 \text{ parts/hour/machine } (\cancel{\text{gross}} \text{ max})$$

The actual cycle time for the machine in operation B ~~is~~ should be 132.92 seconds/part.

$$\frac{3600 \text{ seconds/hour}}{27.0833 \text{ parts/hour}} = 132.92 \text{ seconds/part}$$

If these machines randomly turn on and off in each operation but at an availability of 80%, the percent of time a specific number of machines is operating can be determined by using the binomial distribution. For operation A (table 20) exactly five machines will be operating 32.768% of the time, four machines will be operating 40.96% of the time, or at least four machines will be operating 73.728% of the time. The expected time for the remainder of the machines can be calculated by using the binomial distribution. The time for operation B with six machines can be calculated by the same method (table 21).

By taking a unit of time (hr) the various rates of production over the percentage of time the machines are operating (up) can be calculated for that hour. For example, in operation A five machines are up and running 32.768% of the time; therefore, parts are being produced at the rate of 162.5 parts per hour. This occurs over an expected time period of 19.6608 minutes. ✓

$$(5 \text{ machines}) \left(32.5 \ \frac{\text{parts/hour}}{\text{machine}} = 162.5 \text{ parts per hour}\right)$$

$$(0.32768)\ (60 \text{ minutes}) = 19.6608 \text{ minutes}$$

Since 162.5 parts per hour is 2.70833 parts per minute, operating for 19.6608 minutes produces 53.248 parts.

$$\left(19.6608 \text{ minutes} \ \frac{(162.5 \text{ parts/hour})}{(60 \text{ minutes/hour})} = 53.248 \text{ parts}\right.$$

The above calculations are shown in tables 22 and 23, columns I through V. These columns can be completed by using similar calculations for each row developed for operations A and B starting from the top row and working down. Columns VI through X for each operation can be calculated by starting from the bottom row and working up.

It is unlikely that machines will follow either pattern, but these two conditions represent the extreme of all other conditions that will occur randomly within the binomial distribution. A definition of a maximum condition is when starting out with all machines in a given operation up and running and a minimum condition is when starting out with none of the machines operating. Therefore, columns I through V represent the maximum condition where the majority of parts are produced at the front end of the time interval and columns VI through X represent the minimum condition where the majority of parts are produced at the back end of the time interval.

Operation A producing at the maximum and operation B producing at the minimum are plotted in figure 7. The figure shows that at the time interval of 60 minutes, operation A produces more parts than operation B can accept; therefore, the MHS between the two operations must be able to accept or buffer these parts. The maximum vertical distance between the plot of the two operations represents that buffer and measures approximately 20 parts. Since the maximum and minimum conditions represent the expected extremes of all the situations that might occur, a buffer size of less than 20 parts absorption is actually required in most cases. The question arises as to what is the expected frequency that MAX A and MIN B would occur. MAX A must have a special case of 5, 4, 3, 2, 1 machines up equivalent or similar to a 5-card draw without replacement equal to 5!. MIN B must have 0, 1, 2, 3, 5, 6 equal to a 6-card draw without replacement or 6!. The frequency of a MAX A and MIN B occurring simultaneously would be the product of the two or (5!) (6!) = 86,400. Therefore, this event could occur once every 86,400 time intervals. Since the time interval is 1 hour, a MAX A-MIN B could occur once every 86,400 hours. Some cases may not have five and six machines coupled together. Operations such as forge or heat treatment may have only two machines [(2!)(2!) = 4 hours]. In this case the maximum or minimum condition are met every 4 hours. If a 40-hour capability without exceeding buffer capability is needed, take the buffer quantity calculated for one hour time interval and multiply that value by 40 hours divided by 4 equals 10. In many instances this low number of machines coupled with the complexity of the machines resulting in availabilities lower than 0.8 has led to manufacturers banking as much as one week's production of process pieces to maintian throughput to meet monthly production deliveries.

Consider again operation A and B where the opposite of the above example occurs. Consider the situation where operation A produces at the minimum and operation B produces at the maximum.

A similar situation exists for MIN A and MAX B (fig. 8). Operation B is asking for or accepting more parts than A is producing at that moment. The vertical distance on the chart indicates B will ask for 21 more parts than A is producing during the time interval. If these parts are to be provided by the MHS so as not to adversely affect throughput, then 21 parts must be on the material handling equipment between operations A and B to buffer these operations. Therefore, the material handling space between operations A and B should be 20 vacancies plus 21 fills or 41 spaces.

This buffer is small because we selected two operations that are closely balanced. The buffer is affected according to the unbalance between operations. Nevertheless, the methodology indicates the buffer required. These calculations are programmed on a computer and the charts are printed out. A review of these charts quickly points out unbalanced conditions between operations and any problems that may result in buffer sizes. The buffer sizes obtained from this methodology can then be used as input for buffer sizes to the GENMOD program and the facility tested for monthly production rates.

It was found that by using actual calculated buffer sizes as input to the GENMOD program, more realistic results were immediately obtained based on what would be expected from past experience of similar lines with similar quantities of machine tools. Of most interest was the finding of the relationship between buffer size and predicted monthly production capabilities from the GENMOD program. A buffer size of one-hour production for MSAAP, 260 parts per hour, appears to be more than adequate to meet most conditions. It also appears that even one-half hour production would be adequate in most cases to meet monthly production rates provided a reasonable maintenance program is implemented to keep the equipment operating at reasonable availability values and catastrophic downtime was kept to one hour supplemented by banks in the line as indicated by GENMOD.

The results of the GENMOD also indicated where cost trade-off might be made between the MHS buffer and an additional machine tool to better balance the line, and this factor will also be considered in future design of metal parts production line.

CONCLUSIONS

1. It appears that metal parts production facilities for ammunition projectiles can be simulated by computer programs. The GENMOD program developed at ARRADCOM appears to be the most suitable for such simulations.

2. Effective simulation programs require fairly accurate input data with regard to mean time between failure (MTBF), mean time to repair (MTTR), and buffer size.

3. When provided with good input data, the GENMOD program appears to predict monthly production rates that coincide with past experience for similar production lines.

4. Simulation programs such as GENMOD permit line and sensitivity analysis of parameters previously not available to the productin line designer. Such analysis permits the designer to optimize the production line for throughput and facility cost before it is constructed.

5. Line simulation permits analysis of cost trade-offs for integrated facilities where material handling systems, production equipment, etc., can be traded off one for the other for optimum cost while still maintaining monthly production rates.

6. Simulation programs such as GENMOD point out the importance of preventive maintenance programs by predicting the effect on monthly production caused by catastrophic failures. The trade-off of additional equipment and storage of parts through banks becomes evident with the analysis of a simulation printout.

7. Analysis of GENMOD printouts permits the designer to assess choke points in the production line through the filling or emptying of buffers. The time to fill or empty such buffers can also be seen and evaluated.

8. The methodology developed using the binomial distribution is very helpful in calculating accurate buffer requirements.

9. The binomial distribution methodology also illustrates the advantage of several machines producing at a low rate rather than a few machines producing at a high rate with regard to reliability and meeting expected monthly production rates.

10. The binomial distribution methodology is based upon availability data which is readily obtained in the metal parts equipment industry. There is agreement within the industry as to the reliability of such data.

RECOMMENDATIONS

1. MTTR and MTBF continue to be collected on all metal parts production equipment to improve the reliability of predictions developed under the simulation programs.

2. Simulation programs such as GENMOD continue to be studied, evaluated, and used on existing and future metal parts production lines to improve the performance of the simulation program and to gain a deeper insight into the performane of the production line.

3. The GENMOD program should be used in all future production line layouts before the lines are built.

4. The binomial distribution methodology developed under this project be made available to the material handing industry for future use.

REFERENCES

1. R. Shannon, "Systems Simulation," Prentice-Hall, Englewood Cliffs, NJ, 1975.

2. E. E. Loniewski, "GENMOD, General Production Line Modeling Routine," Technical Report ARPAD-SP-78001, ARRADCOM, Dover, NJ, 1978.

3. G. A. Mihram, "Simulation Statistical Foundations and Methodology," Academic Press, NY, 1972.

BIBLIOGRAPHY

1. M. Barash, J. Talavage, et al., "The Optimal Planning of Computerized Manufacturing Systems," Report No. 1, NSF Grant No. April 1974 15256, Purdue University, November 1975.

2. S. Greenberg, GPSS Primer, Wiley, NY, 1972.

3. P. J. Kiviat, R. Villaneuva, and H. M. Markowitc, "Simscript LL. 5 Programming Language," Rand Corp., Santa Monica, CA, 1968.

4. J. Lenz, "General Computerized Manufacturing System Simulator," MS Thesis, Purdue University, May 1977.

5. E. E. Loniewski, "GENMOD, General Production Line Modeling Routine," Technical Report ARPAD-SP-78001, ARRADCOM, Dover, NJ, 1978.

6. G. A. Mihram, "Simulation Statistical Foundations and Methodology," Academic Press, NY, 1972.

7. H. Mize and J. Cox, "Essentials of Simulation," Prentice-Hall, Englewood Cliffs, NJ, 1968.

8. "MSAAP System Analysis," Mason Chamberlain, Inc., GARD Inc., Niles, IL, 1978.

9. R. Shannon, "Systems Simulation," Prentice-Hall, Englewood Cliffs, NJ, 1975.

10. J. Solberg, "Optimal Design and Control of Computerized Manufacturing Systems," Proceedings of 1976 AIIE Systems Engineering Conference, Boston, MA, 1976.

11. J. Talavage and R. Mayer, "Simulation of a Computerized Manufacturing System," Report No. 4, NSF Grant No. April 1974 15256, Purdue University, August 1976.

Table 1. Mississippi Army Ammunition Plant system summary

	Operation	No. machines per operation	Gross rate per hour (bars)	Gross rate per hour (parts)	*RAM data (hr) MTBF	*RAM data (hr) MTTR	Availability (%)
1005	Load billet	2	10		200.0	5.3	97
1010	Heat billet	2	10		50.0	0.6	99
1015	Hot shear	2		240	200.0	4.0	98
1020	Descale	2		240	200.0	4.0	98
1025	Cabbage			240	6.0	1.5	80
1025A	Backward extrude	2		240	6.0	1.5	80
1025B	Hot pierce slug			240	6.0	1.5	80
1031	Hot inspection	2		240			
1035	Slow cool	2		240	1620.0	30.0	98
1045	Shot blast I.D.	4		125	1583.0	1.0	99
1046	Cold inspection	1		500			
1048	Concentric turn	8		50	90.0	1.4	98.5
1049	Inspection	2		500	500.0	0.5	99
1050	Phosphate and lube	2		225	500.0	8.5	98
1055	Cold draw and coin	2		240	702.0	18.0	97
1056	Alkaline clean	2		225	1200.0	1.0	99
1057	Stress relieve	2		180	1620.0	30.0	98
1058	Dimensionally inspect	2		480	500.0	0.5	99

Table 1. (cont)

	Operation	No. machines per operation	Gross rate per hour (bars)(parts)	*RAM data (hr) MTBF	MTTR	Availability (%)
1060	Bore and center, part cutoff	2	212	200.0	3.0	99
1060A	Remove ring	2	212	1200.0	2.0	99
1065	Rough turn body and band	8	50	34.0	2.3	99
1066	Dimensionally inspect	2	400	500.0	0.5	99
1090	Clean (vapor degrees)	1	350	1200.0	1.0	99
1095	Weld band	18	20	80.0	0.5	99
1100	Rough turn band	4	156	34.0	2.3	94
1101	Dimensionally inspect	2	400	500.0	0.5	99
1103	Acoustically inspect	1	800	500.0	0.5	99
1104	Inspect band hardness	2	180	500.0	0.5	99
1105	Heat treat	2	180	1620.0	30.0	98
1106	Inspect body hardness	2	180	500.0	0.5	99
1110	Bore, face, chf nose	4	110	204.0	5.9	98
1111	Dimensionally inspect	2	400	500.0	0.5	99
1115	Finish turn O.D.	7	55	47.0	2.1	96
1116	Dimensionally inspect	2	400	500.0	0.5	99
1120	Finish bore I.D.	12	28	47.0	2.1	96

Table 1. (cont)

	Operation	No. machines per operation	Gross rate per hour (bars)(parts)	*RAM data (hr) MTBF	MTTR	Availability (%)
1121	Clean (vapor degrees)	1	350	1200.0	1.0	99
1122	Dimensionally inspect	2	360	500.0	0.5	99
1124	Ultrasonically inspect	7	200	500.0	0.5	99
1126	Grind bourrelets	5	70	1000.0	6.0	99
1127	Dimensionally inspect	2	360	500.0	0.5	99
1128*	Double end bore	8				
1130	Slot keyway	18	20	47.0	2.1	96
1131	Clean (vapor degrees)	1	350	1200.0	1.0	99
1135	Dimensionally inspect	2	360	500.0	0.5	99
1140	Bore and thread bar	14	26	550.0	8.0	99
1145	Thread nose	14	15	550.0	8.0	99
1146	Dimensionally inspect	2		500.0	0.5	99
1146A	Dimensionally inspect			500.0	0.5	99
1155	Phosphate	2	225	500.0	8.0	98
1160	Fiberglass wrap and cure	2	160	20.0	1.0	95
1161	Torque test	1	20	500.0	0.5	99
1165	Turn fiberglass	7	53	900.0	22.0	98
1166	Dimensionally inspect	2	360	500.0	0.5	99

Table 1. (cont)

	Operation	No. machines per operation	Gross rate per hour (bars)(parts)	*RAM data (hr) MTBF	MTTR	Availability (%)
1170	Finish band turn	4	80	47.0	2.1	96
1171	Dimensionally inspect	2	320	500.0	0.5	99

* Operation not included in GARD simulation study.

Table 2. 105-mm downtime record sheet

No. 1 Forge

Time down	Time started	Reason for down and operation description	Downtime (min) maint.	Downtime (min) prod.
	2:55	Forge running - water O.K.		
4:00	4:01	Change no. 3 ejector cap		1
4:35	4:40	H.P. generator kicked out (elec.)	5	
4:41		Two billets no. 1 pot - reverse		
	4:51	Press pull cold billets		10
4:53		Press kicking out on ejector up		
		Check timing cams (elect.)		
		Sheared bolts in ejector coupling		
		Press empty - (maint.) repair		
		Grease fitting on north bed		
		Bearing - (plumber)		
		Change pierce punches		
	5:43	Change cabbage punch	40	10

Table 3. Kolmogorov-Smirnov Goodness-Of-Fit Test

Time between failures		Time to repair	
Interval	Theoretical minus observed	Interval	Theoretical minus observed
1	0.0026	1	0.1329
2	0.0072	2	0.1666
3	0.0208	3	0.1111
4	0.0269	4	0.0668
5	0.0329	5	0.0371
6	0.0369	6	0.0142
7	0.0314	7	0.0000
8	0.0456	8	0.0215
9	0.0534	9	0.0013
10	0.0402	10	0.0001
11	0.0411	11	0.0018
12	0.0335	12	0.0026
13	0.0276	13	0.0021
14	0.0242	14	0.0008
15	0.0227	15	0.0020
		16	0.0022

Table 4. Proveout data collection

INSTALLATION (1) Norris	DATA COLLECTION OPERATION 10177 #235 Machine Body Undercut (3)	NO. UNITS PRODUCED (16)	POUNDS ____ (17) PARTS ____ OTHER ____

(4) PAGE 1 OF 1	STATION NO. (5) 070	START TIME OF SHIFT (6) 0730	END TIME OF SHIFT (15) 1530	RATE (14) 1-03	ACCEPT (18) 280	REJECTS (19) 0

DATE (7)	EVENT TIME (8)	EVENT CODE (9)	DURATION (10)		REMARKS (11)	(12) # MP	(13) EQUIPMENT FAILURE CODE
			MIN.	SEC. 1/100			
71079	0730	6	28	-	Out of parts		
	0825	3	16	-	Part out of spec. machine adjustment		
	0915	2	3	30	Break		
	1025	6	21	-	Out of parts		
	1149	6	11	-	Out of parts		
	1200	2	26	-	Lunch		
	1352	6	18	-	Out of parts		
	1419	6	6	-	Out of parts		
	1510	6	7	43	Out of parts		
	1530	1			End of shift		

EVENT CODES (2)	1. END OF SHIFT 2. BREAK/LUNCH 3. CORRECTIVE MAINTENANCE 4. END OF TEST	5. PREVENTIVE MAINTENANCE 6. ADMINISTRATIVE (STATE REASON) 7. ARRADCOM RESERVED 8. OPERATIONAL DOWNTIME (TOOL CHANGE)	MP - MAINTENANCE PERSONNEL	SIGNATURE (20) TYPE NAME (2)

MAR 80

Table 5. Daily statistics for finish turn band-1 (Station 105 at Norris)

Date	Scheduled uptime (min)	Total Breaks	Total down (min)	Actual uptime (min)	Availa-bility (%)	MTBF (min)	MTTR (min)	Total failures	Total rejects	Total processed	Produc-tion rate
06/12/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06/13/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06/14/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06/21/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06/25/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06.26/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06/28/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
06/29/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
07/09/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
07/10/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
07/11/79	367.0	113.0	240.0	127.0	0.34605	127.00	240.00	1	8	46	0.72
07/12/79	380.0	100.0	62.0	318.0	0.83684	106.00	20.67	3	0	210	0.83
07/13/79	410.0	70.0	20.0	390.0	0.95122	195.00	10.00	2	5	200	0.71
TOTALS	5707.0	283.0	4872.0	835.0	0.14631	52.19	304.50	16	13	456	

NOTE: 465 parts/5707 min = 4.8 parts hr

Table 6. Daily statistics for finish turn band-2 (Station 106 at Norris)

Date	Scheduled uptime (min)	Total breaks (min)	Total down (min)	Actual uptime (min)	Availa-bility (min)	MTBF (min)	MTTR (min)	Total failures	Total rejects	Total processed	Produc-tion rate
06/12/79	450.0	30.0	201.0	249.0	0.55333	24.90	18.40	10	0	225	0.78
06/13/79	0.0	455.0	0.0	0.0	0.00000	0.00	0.00	0	0	0	
06/14/79	415.0	65.0	29.0	386.0	0.93012	96.50	7.25	4	12	220	0.74
06/15/79	435.8	44.3	0.0	435.8	1.00000	435.80	0.00	0	0	243	0.82
06/18/79	430.0	50.0	14.1	415.9	0.96717	103.98	3.53	4	1	320	0.81
06/19/79	382.8	97.2	27.0	355.9	0.92956	177.95	13.50	2	0	241	0.78
06/20/79	440.5	39.5	0.0	440.5	1.00000	440.50	0.00	0	0	301	0.60
06/21/79	440.7	39.3	35.0	405.7	0.92057	202.85	17.50	2	0	310	0.78
06/22/79	450.1	29.9	30.2	419.9	0.93290	209.95	15.10	2	0	294	0.75
06/25/79	455.0	25.0	0.0	455.0	1.00000	455.00	0.00	0	1	276	0.84
06/26/79	455.0	25.0	0.0	455.0	1.00000	455.00	0.00	0	5	232	0.83
06/27/79	371.2	108.8	8.5	362.7	0.97710	181.35	4.25	2	0	263	0.80
06/28/79	371.9	108.1	29.7	342.2	0.92027	68.44	5.94	5	0	295	0.82
06/29/79	445.0	35.0	47.2	397.8	0.89397	56.83	6.74	7	0	265	0.79
07/09/79	442.0	38.0	0.0	442.0	1.00000	442.00	0.00	0	0	256	0.46
07/10/79	437.0	43.0	113.0	324.0	0.74142	64.80	19.00	5	0	213	0.71
07/11/79	434.0	46.0	0.0	434.0	1.00000	434.00	0.00	0	0	230	0.76
07/12/79	455.0	0.0	455.0	0.0	0.00000	0.00	455.00	1	0	0	
07/13/79	445.0	35.0	40.0	405.0	0.91011	81.00	8.00	5	5	102	0.86
TOTALS	7756.0	1314.1	1029.7	6726.4	0.86725	137.27	20.30	49	24	4286	

NOTE: 4286 parts/7756 min = 33.15 parts/hr
Operation Finish Turn Band (305) = 33.15 + 4.8 = 37.95 parts/hr

Table 7. Station summary for Norris Industries

Operation by machine	MTBF (min)	MTTR (min)	Availability (%)
HEAT BILLET	158.1	56.7	0.73588
UPSET + BACKWARD EXTRUDE	158.6	58.6	0.69488
IRON	282.2	16.2	0.93921
PIERCE	790.2	189.7	0.80637
ROUGH TURN OD - 1	327.6	27.9	0.91311
ROUGH TURN OD - 2	212.9	60.6	0.77504
MACH AFT END - 1	239.7	23.8	0.90540
MACH AFT END - 2	150.0	27.1	0.83854
ROUGH BORE NOSE - 1	507.9	9.6	0.98042
ROUGH BORE NOSE - 2	456.5	15.6	0.96248
ROUGH TURN OGIVE - 1	340.4	51.8	0.86372
ROUGH TURN OGIVE - 2	454.4	128.0	0.77588
WELD BAND - 1	96.5	8.9	0.89453
WELD BAND - 2	207.2	12.7	0.91721
WELD BAND - 3	125.6	23.1	0.79940

Table 7. (cont)

Operation by machine	MTBF (min)	MTTR (min)	Availability (%)
TURN OD - FACE - 1	104.5	16.7	0.85331
TURN OD - FACE - 2	110.5	11.5	0.86181
ROUGH TURN ID-OD - 1	662.6	31.7	0.95400
ROUGH TURN ID-OD - 2	737.8	7.6	0.98974
FINISH TURN OD - 1	242.8	22.4	0.89746
FINISH TURN OD - 2	358.3	14.4	0.95796
TURN BOURRELET - 1	1648.7	5.3	0.99583
TURN BOURRELET - 2	975.5	4.3	0.99442
MACH BODY UNDERCUT	279.4	14.8	0.94342
FINISH BORE NOSE - 1	175.2	29.4	0.85589
FINISH BORE NOSE - 2	307.2	32.9	0.89959
LONG BORE ID - 1	288.8	28.0	0.89118
LONG BORE ID - 2	278.4	76.7	0.77500
LONG BORE ID - 3	465.4	9.9	0.97368
NOSE LENGTH - ROUGH BORE MINOR	3320.4	8.5	0.99350

Table 7. (cont)

Operation by machine	MTBF (min)	MTTR (min)	Availa-bility (%)
SLOT ID + DEBURR - 1	254.3	20.0	0.91954
SLOT ID + DEBURR - 2	269.6	8.6	0.96492
SLOT ID + DEBURR - 3	339.7	12.0	0.95296
SLOT ID + DEBURR - 4	323.0	84.5	0.78376
THREAD NOSE ID - 1	327.4	15.7	0.93516
THREAD NOSE ID - 2	295.8	13.5	0.92720
FINISH AFT END - 1	149.6	27.9	0.84011
FINISH AFT END - 2	160.6	9.7	0.93838
FINISH TURN BAND - 1	52.2	304.5	0.14631
FINISH BURN BAND - 2	137.3	20.3	0.86725
FIBERGLASS WRAP - 1	133.4	9.7	0.92655
FIBERGLASS WRAP - 2	91.9	6.6	0.92924
FINISH TURN FIBERGLASS - 1	184.1	48.1	0.79169
FINISH TURN FIBERGLASS - 2	288.0	45.4	0.83813

Table 7. (cont)

Operation by machine	MTBF (min)	MTTR (min)	Availability (%)
AIRTEST	1472.0	9.3	0.99376
PAINT SUBASSEMBLY	419.5	11.0	0.95588
TURN OD	1588.7	7.2	0.99056
EDDY CURRENT	7973.5	0.0	1.00000
DRILL	7989.6	0.0	0.99962
THREAD OD	1987.8	13.3	0.99224
MACH FORWARD END	897.2	96.5	0.89992
MACHINE OGIVE	3734.5	16.0	0.98639
CUT THREAD	507.9	19.1	0.95768

Table 8. System summary

Operation by machine	MTBF (min)	MTTR (min)	Availability (%)
HEAT BILLET	158.1	56.7	0.73591
UPSET + BACKWARD EXTRUDE	158.6	58.6	0.69490
IRON	282.2	16.2	0.93922
PIERCE	790.2	189.7	0.80638
ROUGH TURN OD - 2	263.5	46.2	0.84514
MACH AFT END - 2	185.5	25.8	0.87141
ROUGH BORE NOSE - 2	482.2	12.6	0.97185
ROUGH TURN OGIVE - 2	383.8	80.8	0.82177
WELD BAND - 3	124.7	14.3	0.86526
TURN OD - FACE - 2	105.4	15.9	0.85468
ROUGH TURN ID-OD - 2	697.3	20.6	0.97113
FINISH TURN OD - 2	291.0	19.1	0.92751
TURN BOURRELET - 2	1228.0	4.7	0.99513
MACH BODY UNDERCUT	279.4	14.8	0.94343
FINISH BORE NOSE - 2	225.7	30.7	0.87813

Table 8. (cont)

Operation by machine	MTBF (min)	MTTR (min)	Availa-bility (%)
LONG BORE ID - 3	330.0	41.1	0.87750
NOSE LENGTH - ROUGH BORE MINOR	3320.5	8.5	0.99351
SLOT ID + DEBURR - 4	291.3	28.7	0.90202
THREAD NOSE ID - 2	310.9	14.5	0.93119
FINISH AFT END - 2	155.2	18.6	0.88946
FINISH TURN BAND - 2	116.3	90.3	0.56164
FIBERGLASS WARP - 2	108.0	7.8	0.92795
FINISH TURN FIBERGLASS - 2	224.2	47.1	0.81405
AIRTEST	1472.0	9.3	0.99376
PAINT SUBASSEMBLY	419.5	11.0	0.95589
TURN OD	1588.7	7.2	0.99056
EDDY CURRENT	7973.5	0.0	1.00000
DRILL	7989.6	0.0	0.99962
THREAD OD	1987.8	13.3	0.99225
MACH FORWARD END	897.2	96.5	0.89993
MACHINE OGIVE	3734.5	16.0	0.98638
CUT THREAD	507.9	19.1	0.95767

LOWER BOUND ON SYSTEM AVAILABILITY =0.0274 TOTAL FAILURES = 1014 SYSTEM MTTR - 30.22

Table 9. Norris industrial unlimited buffer summary

Maximum buffer contents

(1= 121.)	(2= 58.)	(3= 207.)	(4= 217.)	(5= 20.)	(6= 54.)
(7= 61.)	(8= 594.)	(9= 26.)	(10= 88.)	(11= 64.)	(12= 6338.)
(13= 435.)	(14= 19.)	(15= 68.)	(16= 88.)	(17= 251.)	(18= 44376.)

Average buffer contents

(1= 25.)	(2= 17.)	(3= 41.)	(4= 50.)	(5= 13.)	(6= 14.)
(7= 13.)	(8= 254.)	(9= 12.)	(10= 21.)	(11= 13.)	(12= 3257.)
(13= 93.)	(14= 10.)	(15= 14.)	(16= 19.)	(17= 44.)	(18= 22013.)

Final buffer contents

(1= 18.)	(2= 17.)	(3= 10.)	(4= 58.)	(5= 17.)	(6= 20.)
(7= 19.)	(8= 72.)	(9= 13.)	(10= 13.)	(11= 13.)	(12= 6324.)
(13= 435.)	(14= 10.)	(15= 10.)	(16= 50.)	(17= 13.)	(18= 44376.)

Table 10. Control point data

Control point	Entries	Exits	Maximum input	Maximum output
1	2	2	16.3	16.7
2	2	2	16.7	15.9
3	2	2	15.9	18.6
4	2	3	18.6	15.6
5	3	1	15.6	15.0
6	1	2	15.0	23.1
7	6	2	23.1	22.8
8			22.8	12.8

Table 11. Simulation results of unlimited versus actual buffers

	Unlimited buffers		Actual buffers	
Buffers	Average	Maximum	Average	Maximum
4	50	217	85	122
5	13	20	485	600
6	14	54	550	600
8	254	594	15	19*
12	3257	6338	43	46*

* By rounding off partially made parts per BTI, numbers may be slightly over maximum limits stated.

Table 12. Mississippi Army Ammunition Plant line simulation data

	Operation	No. machine	Gross rate (parts/hr)	RAM data (min) MTBF	MTTR	Availability (%)
1005	LOAD BILLET	2	240	4800.00	240.0	0.9524
1010	HEAT BILLET	2	240			
1015	HOT SHEAR	2	240	53.02	27.27	0.6566
			a	b		
1020	DESCALE	2	240	59.08	13.64	0.8124
1025	CABBAGE, BACKWARD EXTRUDE, PIERCE	2	240			
1035	SLOW COOL	2	240			

[a] Operations combined as one system.

[b] Data is both with and without catastrophic failures.

Table 12. (cont)

Operation		No. machine	Gross rate (parts/hr	RAM data (min) MTBF	MTTR	Availability (%)
1045	SHOT BLAST	2	198.0	520.0	60.0	0.8966
1048	CONC. TURN	6	55.2	263.5	46.0	0.8978
1049	DIMENSIONAL INSPECT	1	500	400.0	10.0	0.9756
1050	PHOS & LUBE	2	165	9600.0	60.0	0.9938
1055	COLD DRAW	2	185	226.0	40.0	0.8496
1058	STRESS RELIEVE & COOL	2	164	7500.0	60.0	0.9921
1060	I.D. BORE NOSE & CUTOFF	5	72	263.5	46.0	0.8508
1065	ROUGH TURN BODY	6	54	263.5	46.0	0.8508
1066	DIMENSIONAL INSP.	2	400	400.0	10.0	0.9756
1090	CLEAN	1	290	7500.0	60.0	0.9921
1095	WELD BAND	18	20	124.5	14.5	0.8971
1100	ROUGH TURN BAND	4	81.6	137.5	20.5	0.8712
1101	DIMENSIONAL IN-SPECT	1	400	400	10.0	0.9756

Table 12. (cont)

Operation		No. machine	Gross rate (parts/hr)	RAM data (min) MTBF	MTTR	Availability (%)
1105	HEAT TREAT	2	165	9600.0	60.0	0.9938
1106	DIMENSIONAL IN-SPECT	2	260	400.0	10.0	0.9756
1115	FINISH TURN	6	55.2	137.5	20.5	0.8712
1116	DIMENSIONAL INSPECT	7	400	400.0	10.0	0.9756
1117	FINISH BORE	10	34.8	330.0	41.0	0.8892
1118	DIMENSIONAL IN-SPECT	2	360	400.0	10.0	0.9756
1120	GRIND BOURRELETS	5	65	297.0	33.0	0.9000
1121	DIMENSIONAL INSPECT	2	360	400.0	10.0	0.9956
1122	CLEAN	1	290	7500.0	60.0	0.9921
1124	DEFECT INSP.	3	120	400.0	10.0	0.9756
1128	DOUBLE END BORE	8	40.8	225.5	30.5	0.8803
1129	DIMENSIONAL INSP.	2	360	400.0	10.0	0.9756

Table 12, (cont)

Operation		No. machine	Gross rate (parts/hr)	RAM data (min) MTBF	MTTR	Availability (%)
1130	SLOT I.D. AND DE-BURR	20	16.8	291.5	28.5	0.9103
1131	CLEAN	1	290	7500.0	60.0	0.9921
1135	DIMENSIONAL INSP.	2	360	400.0	10.0	0.9756
1155	PHOSPHATE	2	165	9600.0	60.0	0.9938
1160	FIBERGLASS WRAP	2	174	108.0	36.0	0.8780
1165	FINISH TURN FIBERGLASS	5	69.6	224.0	47.0	0.8264
1166	DIMENSIONAL INSP.	2	380	400.0	10.0	0.9756
1170	FINISH TURN BAND	5	81.6	137.5	20.5	0.8712

Table 13. Mississippi Army Ammunition Plant simulation, unlimited buffers

Buffer	Operation	Maximum	Average
2	Shot blast to concentric turn	16,455	6,826
4	Phosphate to cold draw	1,317	164
7	Bore nose to R.T. body	2,902	1,628
8	R.T. body to clean	589	149
15	Grind bourrelets to clean	653	108
21	Fiberglass wrap to turn	931	211

Table 14. Simulation Summary for Mississippi Army Ammunition Plant

Category	No. of machines	Total failures (min)	Total downtime (min)	Total uptime (min)	Average availability (%)	Average stop time (min)
1035	2	772	4058	7942	66.18	0.0
1045	2	108	1328	10672	88.93	188.5
1048	6	561	5125	30875	85.76	2.0
1050	2	9	91	11909	99.24	3.0
1055	2	221	1607	10193	84.94	3.5
1058	2	3	25	11965	99.79	67.0
1060	5	480	4381	25619	85.40	39.4
1065	6	559	4913	31087	86.35	16.3
1090	1	8	47	5953	99.22	19.0
1095	16	3924	10430	97570	90.34	54.9
1100	4	758	2730	21270	88.63	44.3
1105	2	3	41	11959	99.66	48.0
1115	6	1144	4475	31525	87.57	24.5
1117	10	858	6531	53469	89.12	22.4
1120	5	442	2774	27226	90.75	22.2
1122	1	6	46	5954	99.23	26.0
1128	8	952	5593	42407	88.35	46.0

Table 14. (cont)

Category	No. of machines	Total failures (min)	Total downtime (min)	Total uptime (min)	Average availability (%)	Average stop time (min)
1130	20	1933	10475	109525	91.26	50.3
1131	1	3	8	5992	99.87	44.0
1155	2	6	91	11909	99.24	48.0
1160	2	464	1342	10658	88.82	44.5
1165	5	579	4822	25178	83.93	22.4
1170	5	998	3835	26165	87.22	27.2

Table 15. Mississippi Army Ammunition Plant buffer analysis

Run	Description	Buffers	Total hangers	Downtime (hr)	Production rate (K)
1	With inspection	130	4,420	1	127
2	With inspection	260	8,840	1	130
3	With inspection	130	4,420	8	105
4	With inspection	260	8,840	8	113
5	Without inspection	130	2,860	1	128
6	Without inspection	260	5,720	1	132
7	Without inspection	30	660	8	76
8	Without inspection	65	1,430	8	87
9	Without inspection	130	2,860	8	96
10	Without inspection	195	4,290	8	107
11	Without inspection	260	5,720	8	114
12	Without inspection	520	11,440	8	122

Table 16. Louisiana Army Ammunition Plant metal parts system summary

Operation		No. machine	Gross rate	MTBF (hr)	MTTR (hr)	Availability (%)
1020	Nick beak	1	290	790.2 220.0	189.7 40.0	80 85
1040	Heat mults	1	180	158.1	56.7	74
1060	Hot forging (combine)	1	180	60.0	13.0	82
1110	Slow cooling	1	180	790.2 158.1	189.7 56.7	80 73
1120	Shot blast I.D.	2	180	158.1	56.7	74
1210	Rough turn OD x partial cut off	4	48	263.5	46.2	85
1220	Remove ring	1	240	697.3	20.6	97
1250	Weld overlay band	6	22	124.7	14.3	90
1260	Rough turn band	2	93	697.3	20.6	97
1270	Austenitize, quench, temper and cooling	1	180	790.2 158.1	189.7 56.7	80 74
1280	Body hardness test	2	100	1228.0	4.7	99
1320	Bore, face, and chamfer nose	2	92	225.7	30.7	88
1330	Finish turn body O.D.	6	36	291.0	19.1	94
1340	Finish bore cavity	3	57	330.0	41.1	89
1350	C'bore, face and chamfer base end	3	66	225.7	30.7	88
1360	Slot and deburr	10	17	291.3	28.7	91
1380	Magnetic particle inspection	2	100	1228.0	4.7	99

Table 16. (cont)

Operation		No. machine	Gross rate	MTBF (hr)	MTTR (hr)	Availability (%)
1390	Thread nose and base ends	4	44	310.9	14.5	95
1400	Grind bourrelets	3	58	1228.0	4.7	99
1420	Wash and phosphatize body	1	225	1228.0	4.7	99
1440	Wrap and cure fiberglass	2	100	108.0	7.8	93
1460	Grind fiberglass	2	87	224.2	47.1	92
1470	Finish turn rotating band	3	58	137.3	20.3	87
1490	Stamp identity	1	240	1228.0	4.7	99

Table 17. Louisiana Army Ammunition Plant unlimited buffer summary

Average buffer contents

(1=	7218.)	(2=	115.)	(3=	614.)	(4=	12.)	(5=	71.)	(6=	6.)
(7=	1156.)	(8=	3.)	(9=	595.)	(10=	2.)	(11=	55.)	(12=	4.)
(13=	49.)	(14=	9.)	(15=	14.)	(16=	2.)	(17=	7.)	(18=	2.)
(19=	2.)	(20=	3.)	(21=	17.)	(22=	30.)	(23=	2.)	(24=	8664.)

Table 18. Louisiana Army Ammunition Plant--varied MTBF and MTTR values (slow cool and heat treat)

Run	MTBF (hr)	MTTR (hr)	Availability (%)	Monthly production rates
BAESFBF	158.1	56.7	73	56253
BAESF63	790.2	189.7	80	55702

Table 19. Louisiana Army Ammunition Plant--varied buffer limits

Run	Buffer size	Monthly production rate
BAESF69	No limit	59,717
BAESF80	500 and 88 (actual designed rate)	51,384
BAESF32	500 and 88 (actual designed rate)	58,581

Table 20. Percentage of time various numbers of machines are operating (operation A)

		%	Σ%
$\frac{120}{120\times 1}=$ $\frac{5!}{5!0!}$	$\left[0.8\right]^5 \left[0.2\right]^0$ =	0.32768	0.32768
$\frac{5!}{4!1!}$	$\left[0.8\right]^4 \left[0.2\right]^1$ =	0.4096	0.73728
$\frac{5!}{3!2!}$	$\left[0.8\right]^3 \left[0.2\right]^2$ =	0.2048	0.94208
$\frac{5!}{2!3!}$	$\left[0.8\right]^2 \left[0.2\right]^3$ =	0.0512	0.99328
$\frac{5!}{1!4!}$	$\left[0.8\right]^1 \left[0.2\right]^4$ =	0.0064	0.99968
$\frac{5!}{0!5!}$	$\left[0.8\right]^0 \left[0.2\right]^5$ =	0.00032	1.00000

M = np = (5)(0.8) = 4.0 machines

(4.0) (32.5) = 130 parts per hour throughput

Design production rate = 32.5 parts per hour per machine

Table 21. Percentage of time various numbers of machines are operating (operation B)

		%	Σ%
$\frac{6!}{6!0!}\left[0.8\right]^{6}\left[0.2\right]^{0}$	=	0.262144	0.262144
$\frac{6!}{5!1!}\left[0.8\right]^{5}\left[0.2\right]^{1}$	=	0.393216	0.655360
$\frac{6!}{4!2!}\left[0.8\right]^{4}\left[0.2\right]^{2}$	=	0.245576	0.0901120
$\frac{6!}{3!3!}\left[0.8\right]^{3}\left[0.2\right]^{3}$	=	0.08192	0.983040
$\frac{6!}{2!4!}\left[0.8\right]^{2}\left[0.2\right]^{4}$	=	0.01536	0.998400
$\frac{6!}{1!5!}\left[0.8\right]^{1}\left[0.2\right]^{5}$	=	0.001536	0.999936
$\frac{6!}{0!6!}\left[0.8\right]^{0}\left[0.2\right]^{6}$	=	0.000064	1.000000

$M = np = (6)(0.8) = 4.8$ machines

(4.8)(27.0833) = 130 parts per hour throughput

Design production rate = 27.0833 parts per hour per machine

Table 22. Binomial distribution-operation A

	I	II	III	IV	V	VI	VII	VIII	IX	X
	Machines up	Time (min)	Parts produced	Cumulative time (min)	Cumulative parts produced	Machines up	Time (min)	Parts produced	Cumulative time (min)	Cumulative parts produced
A	5	19.6608	53.248	19.6608	53.248	0	0.0192	0	0.0192	0
B	4	24.576	53.248	44.2368	106.496	1	0.384	0.208	0.4032	0.208
C	3	12.288	19.968	56.5248	126.464	2	3.072	3.328	3.4752	3.536
D	2	3.072	3.328	59.68	129.792	3	12.288	19.968	15.7632	23.504
E	1	0.384	0.208	59.9808	130.000	4	24.576	53.248	40.3392	76.752
F	0	0.0192	0	60.000	130.000	5	19.6608	53.248	60.000	130.000

Parts/minutes/machine = 0.54166667

inversion of columns I - V

Table 23. Binomial distribution-operation B

I	II	III	IV	V	VI	VII	VIII	IX	X
Machines up	Time (min)	Parts produced	Cumulative time (min)	Cumulative parts produced	Machines up	Time (min)	Parts produced	Cumulative time (min)	Cumulative parts produced
6	15.72864	42.5984	15.72864	42.5984	0	0.00384	0	0.00384	0
5	23.59296	53.248	39.3216	95.8464	1	0.09216	0.0416	0.0960	0.0416
4	14.7456	26.624	54.0672	122.4704	2	0.9216	0.832	1.0176	0.8736
3	4.9152	6.656	58.9824	129.1264	3	4.9152	6.656	5.9328	7.5296
2	0.9216	0.832	59.904	129.9584	4	14.7456	26.624	20.6784	34.1536
1	0.09216	0.0416	59.99616	130.0000	5	23.59296	53.248	44.27136	87.4016
0	0.00384	0	60.0000	130.0000	6	15.72864	42.5984	60.0000	130.00

Parts/minutes/machine = 0.4513889

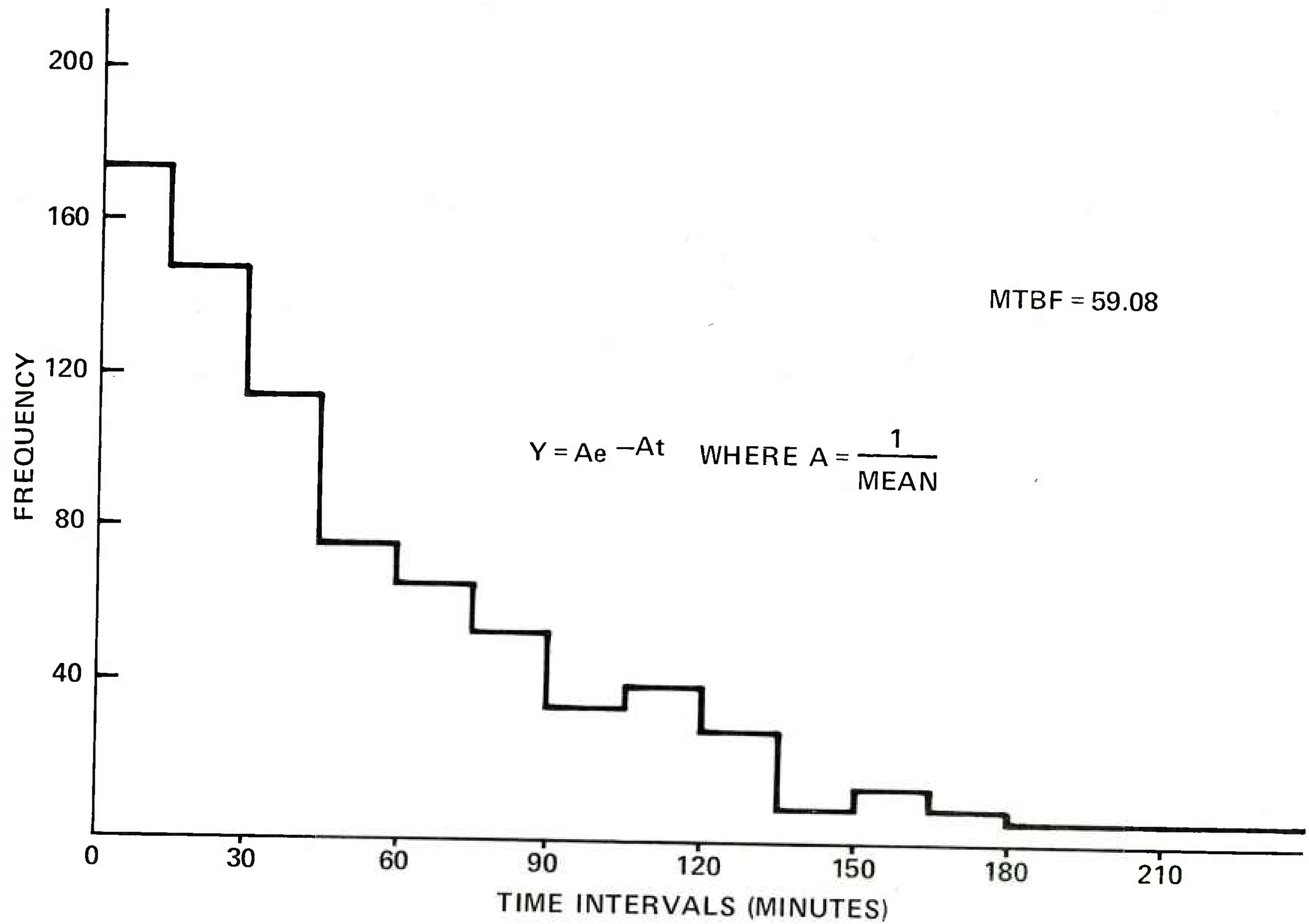


Figure 1. Frequency of failure versus time between failures

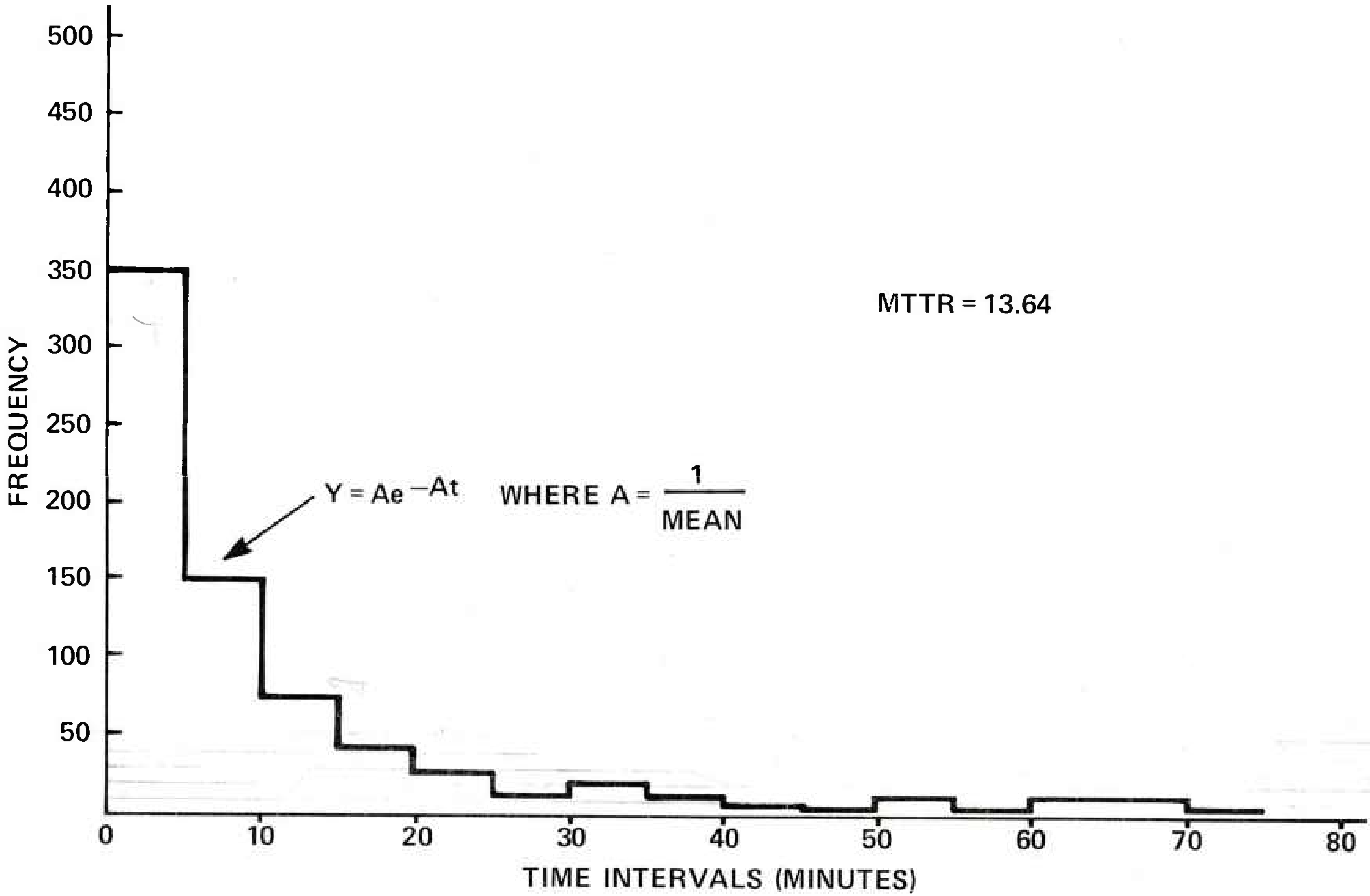
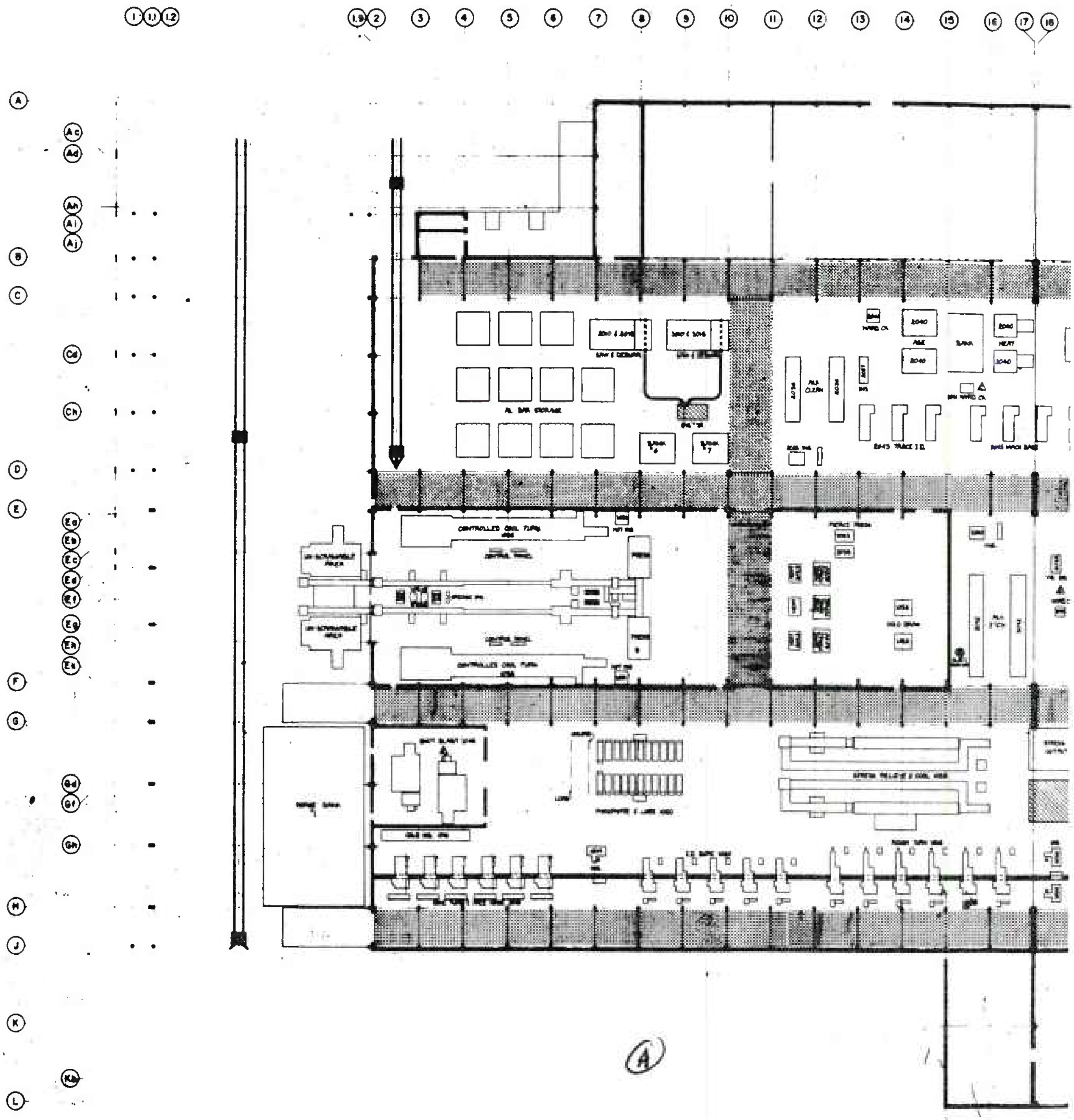
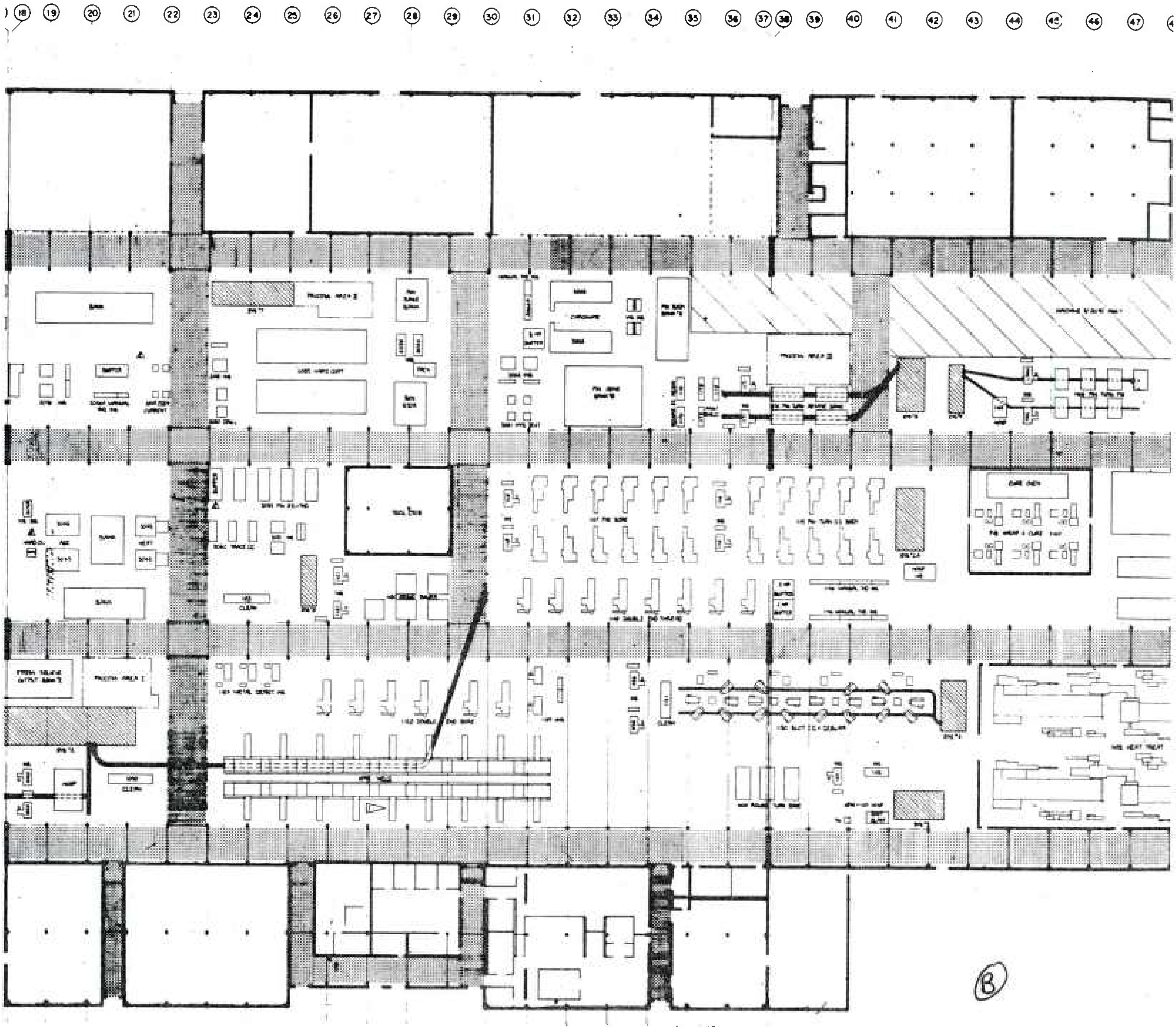


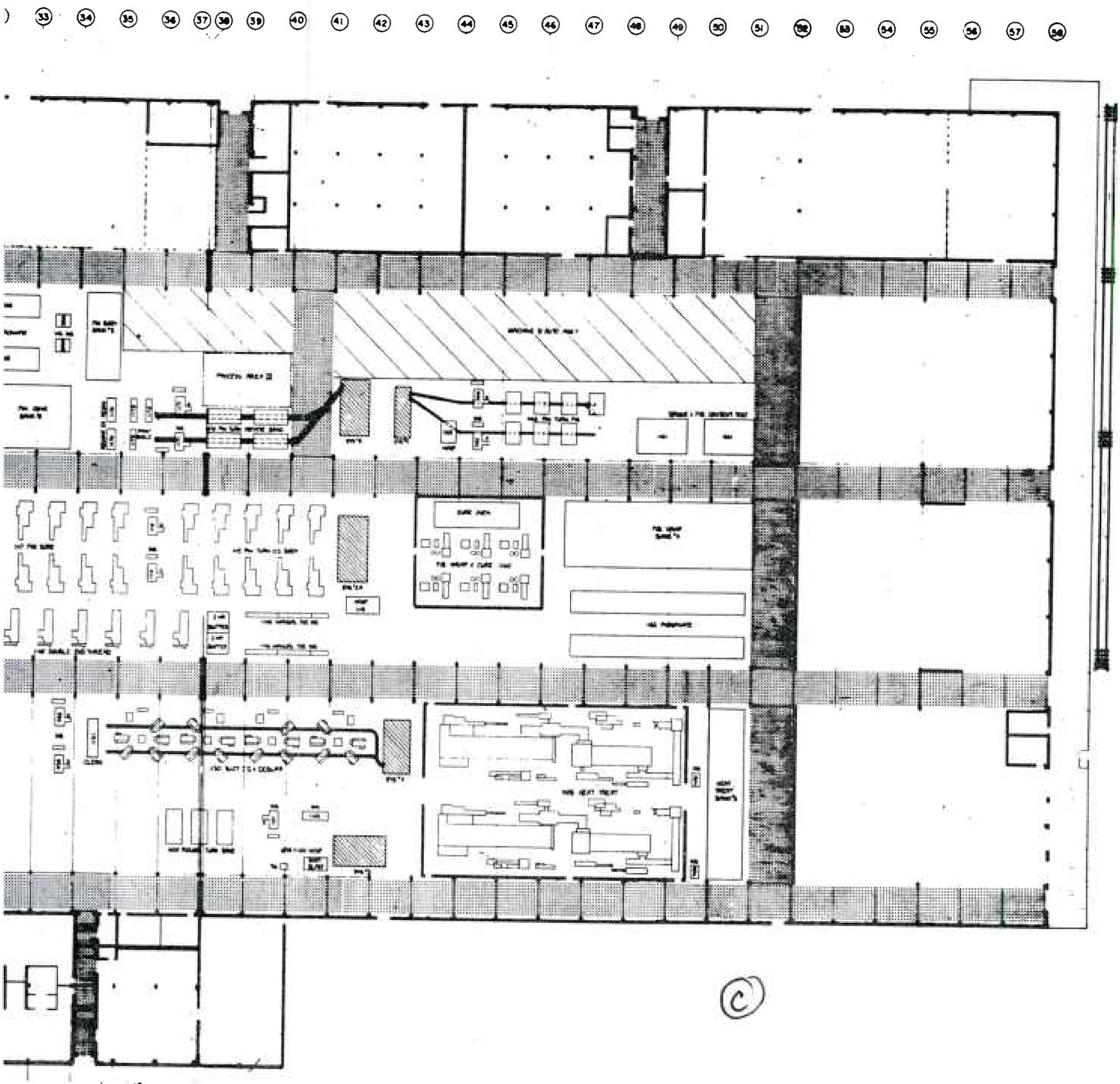
Figure 2. Frequency of repairs versus time to repair



Figure



re 3. Mississippi Army Ammunition Plant 155-mm M483 line


33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
C

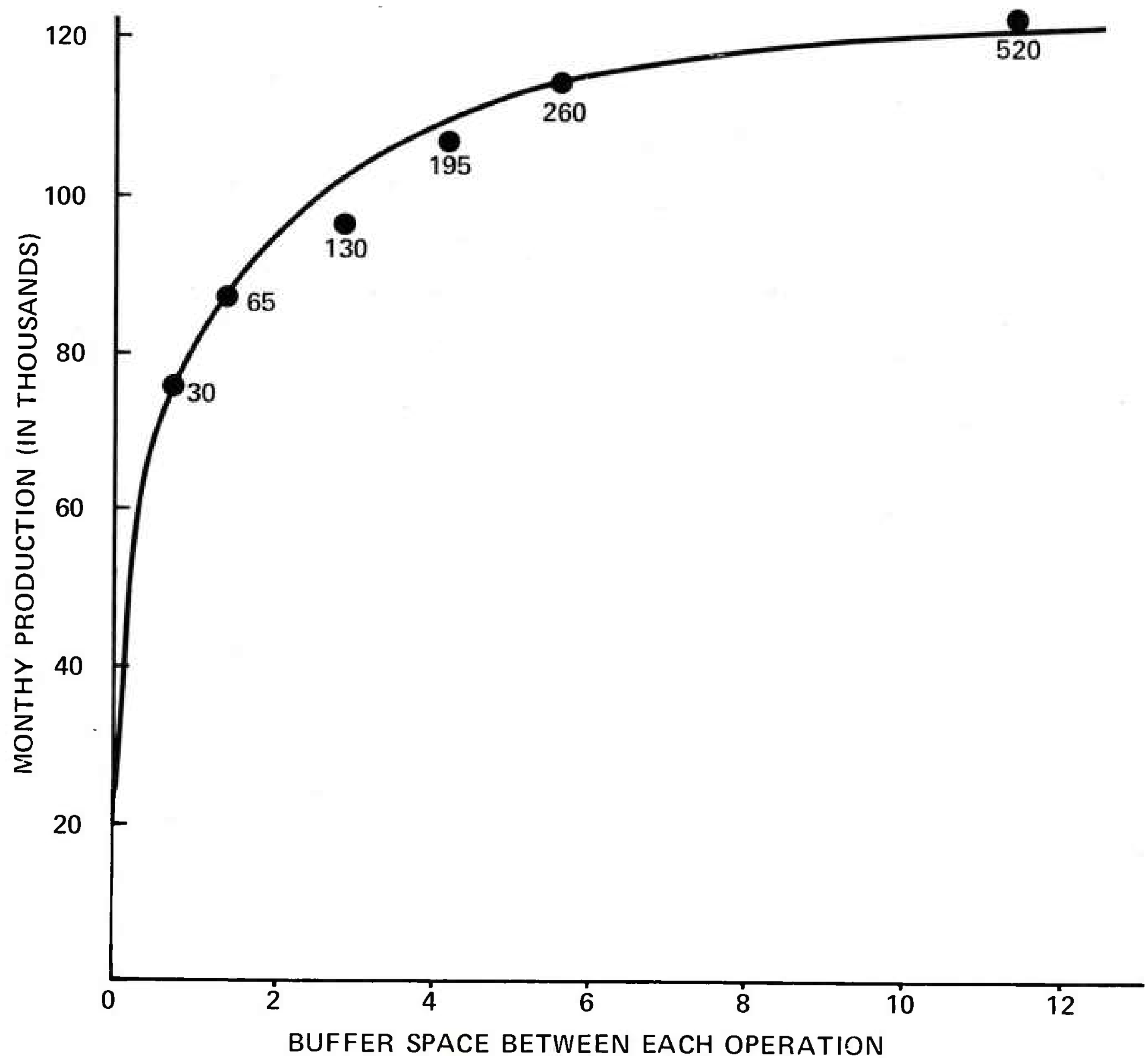


Figure 4. Monthly production throughput versus buffer size (8-hour downtime)

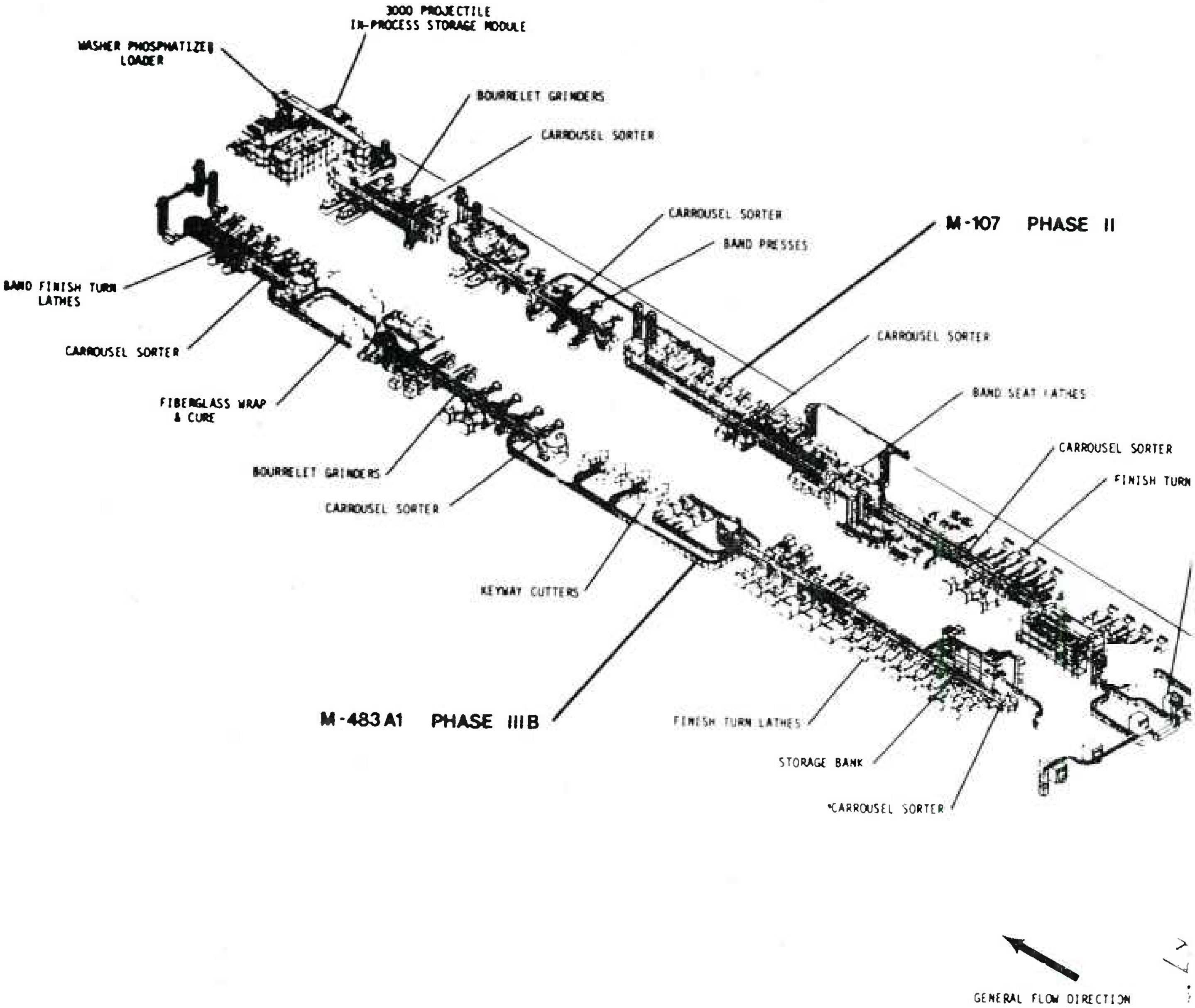
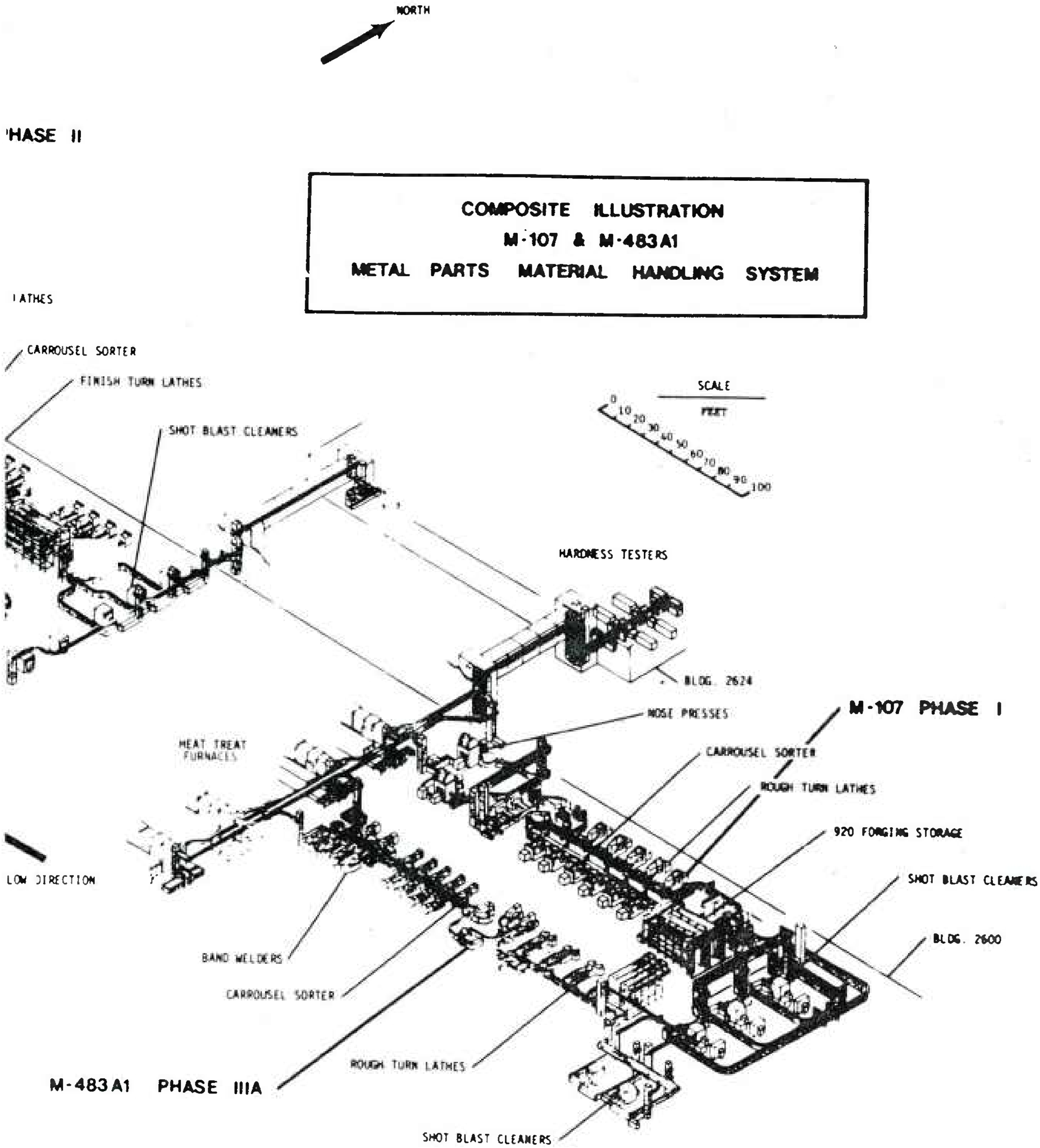


Figure 5. Metal parts material handl
at Louisiana Army Ammuniti

(A)



terial handling system M-107 and M-483A1
rmy Ammunition Plant

(B)

$$(a + b)^n = \sum_{x=0}^{n} \binom{n}{x} b^x a^{n-x}$$

$$f(x) = \binom{n}{x} p^x (1-p)^{n-x} \quad x = 0, 1, 2, \ldots, n$$

p = PROBABILITY MACHINE IS UP

$1-p$ = PROBABILITY MACHINE IS NOT UP

$p + (1-p) = 1$

x, n = NUMBER OF MACHINES IN ONE OPERATION

Figure 6. Binomial distribution

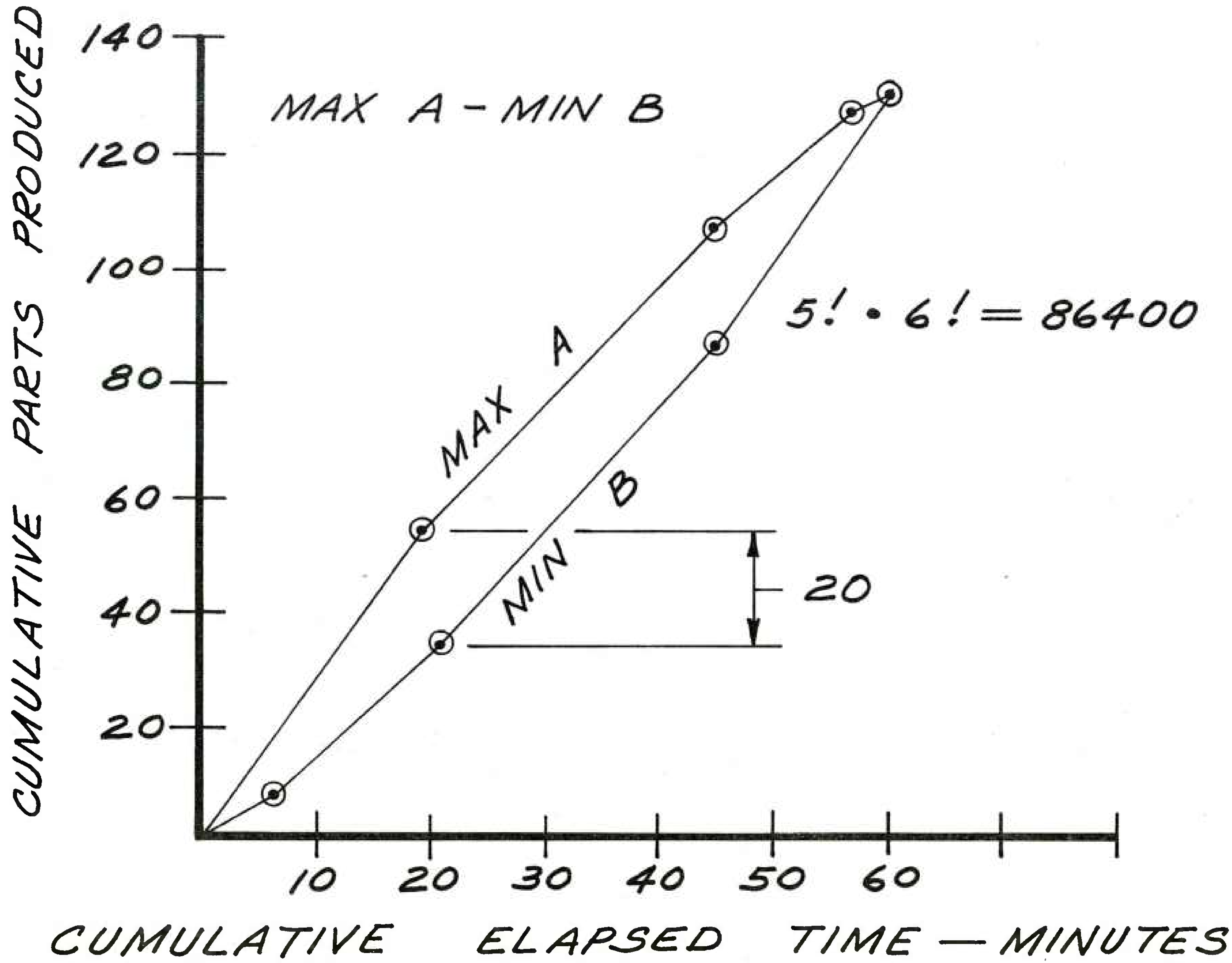


Figure 7. Cumulative parts produced versus cumulative elapsed time (MAX A - MIN B)

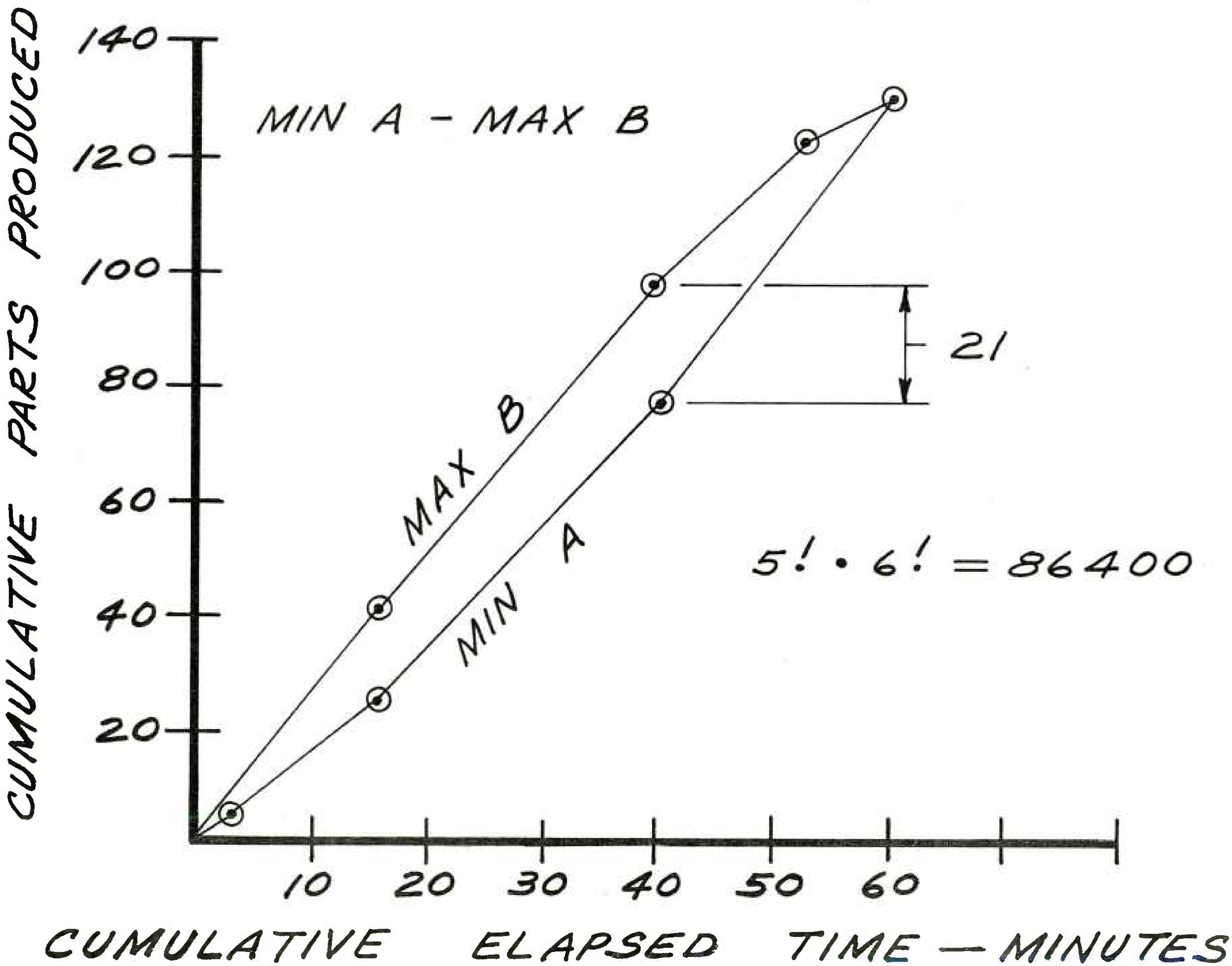


Figure 8. Cumulative parts produced versus cumulative elapsed time (MIN A - MAX B)

DISTRIBUTION LIST

Commander
U.S. Army Armament Research
and Development Command
ATTN: DRDAR-GCL
DRDAR-LCU-M (12)
DRDAR-LCM (2)
DRDAR-TSS (5)
Dover, NJ 07801

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22314

Commander/Director
Chemical Systems Laboratory
U.S. Army Armament Research
and Development Command
ATTN: DRDAR-CLB-PA
DRDAR-CLJ-L
APG, Edgewood Area, MD 21010

Director
Ballistics Research Laboratory
U.S. Army Armament Research
and Development Command
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21005

Chief
Benet Weapons Laboratory, LCL
U.S. Army Armament Research
and Development Command
ATTN: DRDAR-LCB-TL
Watervliet, NY 12189

Commander
U.S. Army Armament Materiel
Readiness Command
ATTN: DRSAR-LEP-L
DRSAR-PPI-W
Rock Island, IL 61299

Director
U.S. Army Materiel Systems
Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Commander
U.S. Army Munitions Production Base
  Modernization Agency
ATTN: SARPM-PBM-EC (2)
Dover, NJ 07801

Commander
Scranton Army Ammunition Plant
ATTN: SARSC-XC (3)
Scranton, PA 18501

Commander
Louisiana Army Ammunition Plant
ATTN: SARLA-EN
Shreveport, LA 71130

Commander
Mississippi Army Ammunition Plant
ATTN: SARMS
Mississippi Mall
Picayune, MS 39466

Director
U.S. Army Production Equipment Agency
ATTN: DRXPE
Rock Island, IL 61201

Director
Industrial Base Engineering Activity
ATTN: DRXIB-MT (3)
Rock Island, IL 61299